Spur Hill Underground Coking Coal Project

Application for a Gateway Certificate

Appendix C
Preliminary Groundwater Assessment

SPUR HILL UNDERGROUND COKING COAL PROJECT:

GATEWAY APPLICATION PRELIMINARY GROUNDWATER ASSESSMENT

FOR

SPUR HILL MANAGEMENT PTY LTD

By

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trading as

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EXECUTIVE SUMMARY

The Spur Hill Underground Coking Coal Project (the Project) is a coal development project targeting the underground resource within Exploration Licence (EL) 7429 in the Upper Hunter Valley, near Muswellbrook.

This report has been prepared for Spur Hill Management to provide a preliminary groundwater assessment of the Project for the purposes of the Gateway process. The assessment relies on numerical modelling of potential risks of mine development in terms of the New South Wales (NSW) Aquifer Interference (AI) Policy and Gateway process requirements. This modelling was undertaken in consideration of the Murray-Darling Basin Commission (MDBC) Groundwater Flow Modelling Guideline (MDBC, 2001) and the relatively new National Guidelines, sponsored by the National Water Commission (Barnett *et al*., 2012).

The scope of this assessment has been developed based on ongoing consultation with the NSW Office of Water, including a briefing and presentation on 23 May 2013.

A full review of the data, literature and conceptual hydrogeology was carried out as a basis for model development. This included review of currently available information on geology, rock mass hydraulic properties, neighbouring mine workings and strata geometry for the area.

The complexity of the numerical groundwater model developed as part of this study is adequate for this preliminary groundwater assessment by simulating contrasts in hydraulic properties and hydraulic gradients that may be associated with changes to the groundwater system as a result of the proposed development.

The key findings of the groundwater assessment with respect to 'highly productive groundwater' are summarised in **Table ES-1**.

Based on the findings of the groundwater assessment, the Project meets the Level 1 Minimal Impact Considerations of the AI Policy for 'highly productive' water associated with the Hunter Alluvium.

The Project falls within the Level 2 Minimal Impact Considerations of the AI Policy for the 'less productive' water source comprising a Permian fractured rock aquifer as more than 2 metres (m) drawdown is predicted at water supply works. Hence, a Groundwater Management Plan will require development to define groundwater level triggers, and a trigger action response plan.

Table ES-1 Summary of AI Policy Assessment – Hunter Alluvium

Aquifer	Alluvial Aquifer (Hunter Unregulated and Alluvial Water Sources)
Category	Highly Productive
Level 1 Minimal Impact Consideration	**Assessment**
<u>Water Table</u> Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic “post-water sharing plan” variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work.	At the time of writing there were no Culturally Significant Sites or high priority Groundwater Dependent Ecosystems (GDEs) in the study area listed in the relevant Water Sharing Plan, i.e. ‘Hunter Unregulated and Alluvial Water Sources’ (version current for 8 March 2013). Hence there are no known risks of mine development to such sites. No drawdown in excess of the criterion within the Hunter Alluvium. **Level 1 minimal impact consideration classification.**
<u>Water pressure</u> A cumulative pressure head decline of not more than 40% of the ”post-water sharing plan” pressure head above the base of the water source to a maximum of a 2m decline, at any water supply work.	N/A (only unconfined conditions in alluvial aquifer).
<u>Water quality</u> Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity. No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. No mining activity to be below the natural ground surface within 200m laterally from the top of high bank or 100m vertically beneath (or the three dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a “reliable water supply”. Not more than 10% cumulatively of the three dimensional extent of the alluvial material in this water source to be excavated by mining activities beyond 200m laterally from the top of high bank and 100m vertically beneath a highly connected surface water source that is defined as a “reliable water supply”.	Mining is predicted to induce leakage of surface water into the Hunter Alluvium. This will, if anything, have a beneficial impact on salinity of the alluvial aquifer. There are therefore no simulated risks of reduced beneficial uses of the Hunter Alluvium as a result of the Project. Nor is there any predicted increase in the salinity of the Hunter River. No proposed mining activity within these specified proximities to the Hunter Alluvium. No proposed excavation of alluvial material proposed. **Level 1 minimal impact consideration classification.**

DOCUMENT REGISTER

Revision	Description	Date
A	Initial draft	20 June 2013
B	1st internally reviewed draft	4 August2013
C	3rd draft	2 September 2013
D	Final draft	22 October 2013
E	Final	20 November 2013

ACKNOWLEDGMENTS

Person	Company	Activity
Chris Nicol	HydroSimulations	Model calibration, reporting and figures.
Will Minchin	HydroSimulations	Impact assessment, reporting and figures.
Tingting Liu and Pollo Zhao		Geological model, and transient predictive model build and simulations.

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1 INTRODUCTION

The Spur Hill Underground Coking Coal Project (the Project) is a coal development project targeting the underground resource within Exploration Licence (EL) 7429. Figure 1 shows the location of the Project. EL7429 is located east of Denman and southwest of Muswellbrook in the Upper Hunter Valley region of New South Wales (NSW).

Spur Hill Management Pty Ltd (SHM) manages the Project on behalf of the joint venture between Spur Hill U.T. Pty Ltd and Spur Hill No. 2 Pty Limited.

The Project is within the Upper Hunter Valley coal corridor which contains a number of operating mines. Significant coal operators in close proximity to the Project include BHP Billiton's Mt Arthur North mine, Anglo Coal's Drayton Mine and Drayton South Project (proposed), and Glencore's Mangoola Mine.

Exploration activities and environmental studies for the Project commenced in early 2012.

The NSW State government recently introduced the 'Gateway process'. This process applies to State Significant Development located on strategic agricultural land (SAL) (Figure 2), as defined in Strategic Regional Land Use Plans (SRLUPs).

The Gateway process will include an assessment of potential impacts on water resources by the Minister for Primary Industries and the Commonwealth Independent Expert Scientific Committee (IESC). The State assessment will focus on the "minimal impact considerations" prescribed in NSW's Aquifer Interference (AI) Policy (2012).

The AI Policy requires estimation of "all quantities of water that are likely to be taken from any water source during and following cessation of the activity and all predicted impacts associated with that activity...". The estimation is to be based on a "simple modelling platform" that the Minister determines to be "fit-for-purpose", where the model makes use of the "available baseline data that has been collected at an appropriate frequency and scale".

This report documents a preliminary groundwater assessment of the Project for the purposes of the Gateway process. The assessment relies on numerical modelling of potential risks of mine development in terms of the AI Policy and Gateway process requirements.

1.1 SCOPE OF WORK

The key tasks for this assessment are:

- Data analysis and conceptualisation of the groundwater system, including assessment of hydrostratigraphic units (HSUs) and their properties, and groundwater recharge and discharge through the flow systems;
- Development of a simple regional-scale 3-dimensional numerical groundwater flow model based on data analysis and conceptual model development;
- Steady-state model calibration to observed groundwater level data, using only a single parameter zone for each hydrostratigraphic unit;
- Transient model verification against observed groundwater level fluctuation data;
- Transient prediction for the mine plan conducted with coarse temporal resolution of the extraction schedule, followed by a minimum 100 year simulation of the post-mining recovery period; and
- Preparation of this Preliminary Groundwater Assessment report for inclusion in the Gateway Application documents that includes assessment of potential groundwater impacts of the Project and cumulative impacts with other existing and approved mines in the area associated with the development.

This assessment focuses on the criteria specified by the AI Policy and the requirements outlined in Table 1.

The scope has been developed based on ongoing consultation with the NSW Office of Water (NOW). HydroSimulations presented to NOW on 23 May 2013, including discussion of:

- Groundwater monitoring network;
- Conceptualisation of the hydrogeological system; and
- Proposed modelling approach for the Gateway Process.

Table 1 Gateway Process Requirements

Requirement	Section Reference
Estimates of all quantities of water that are likely to be taken from any water source on an annual basis during and following cessation of the activity;	Section 5.3
A strategy for obtaining appropriate water licence/s for maximum predicted annual take;	Section 7
Establishment of baseline groundwater conditions including groundwater depth, quality and flow based on sampling of all existing bores in the area potentially affected by the activity, any existing monitoring bores and any new monitoring bores that may be required under an authorization under the Mining Act 1992 or the Petroleum (Onshore) Act 1991;	Section 2
A strategy for complying with any water access rules applying to relevant categories of water access licences, as specified in relevant water sharing plans;	Section 7
Estimates of potential water quality, level, or pressure drawdown impacts on nearby water users who are exercising their right to take water under a basic landholder right;	Section 5.7
Estimates of potential water level, quality or pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources;	Section 5.7
Estimates of potential water level, quality or pressure drawdown impacts on groundwater dependent ecosystems;	Section 5.4
Estimates of potential for increased saline or contaminated water inflows to aquifers and highly connected river systems;	Section 5.8
Estimates of the potential to cause or enhance hydraulic connection between aquifers;	Sections 3.5 and 5.6
Estimates of the potential for river bank instability, or high wall instability or failure to occur;	Not Applicable
Outline of the method for disposing of extracted water (in the case of coal seam gas activities).	Not Applicable
Assess the project against the criteria specified in 'Table 1 – Minimal Impact Considerations for Aquifer Interference Activities' in the Aquifer Interference Policy.	Section 5.10

1.2 PROPOSED MINE DEVELOPMENT

The Project is a proposed underground coal mining operation with a mine life of approximately 25 years, including construction, development and operation. Coal would be mined by the longwall method from a number of seams in the Wittingham Coal Measures. The three target coal seams are the Whynot, Bowfield, and Warkworth Seams.

Expected coal output is about 154 million tonnes of run of mine (ROM) coal over the life of the mine. Maximum yearly production may reach 8 million tonnes per annum (Mtpa).

1.3 WATER REGULATION

The NOW implements water regulation according to the *Water Management Act 2000*, a primary objective of which is sustainable management and use of water resources, balancing environmental, social and economic considerations.

The NOW is in the process of developing Water Sharing Plans (WSPs) throughout the State, which establish rules for sharing and trading both groundwater and surface water between competing needs and users.

The relevant WSPs for the Project are the *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009* and the *Water Sharing Plan for the Hunter Regulated Water Source 2003* (Figure 3), which have been completed. The hard rock (porous rock) aquifers in the Project area are regulated under the *Water Act 1912* as a relevant WSP has not yet commenced.

The NSW AI Policy is designed to provide a framework for the assessment of impacts of the taking of water under a proposed development, such as the Project. The AI Policy divides groundwater sources into “highly productive” and “less productive” categories based on salinity and aquifer yield.

The two water sources identified by the WSP that are directly relevant to the Project are:

- The ‘highly productive’ Hunter Regulated River Alluvial Water Source (Figure 4); and
- The ‘less productive’ Permian (Sydney Basin) porous rock aquifer (Hunter Extraction Management Unit (EMU) / Jerrys and Muswellbrook Management Zones).

The AI Policy also specifies 'minimal impact considerations' for both highly productive and less productive aquifers; these comprise thresholds for watertable and groundwater pressure drawdown, and changes in groundwater and surface water quality. Different minimal impact considerations are specified for highly productive and less productive groundwater for:

- Water supply works;
- Listed Groundwater Dependent Ecosystems (GDEs); and
- Culturally significant sites.

1.4 APPROACH TO THE GATEWAY PROCESS

Under the Gateway process, the AI Policy requires estimation of all water takes and impacts during and following cessation of the proposed activity based on a "simple modelling platform" that the Minister determines to be "fit-for-purpose", based on appropriate baseline data.

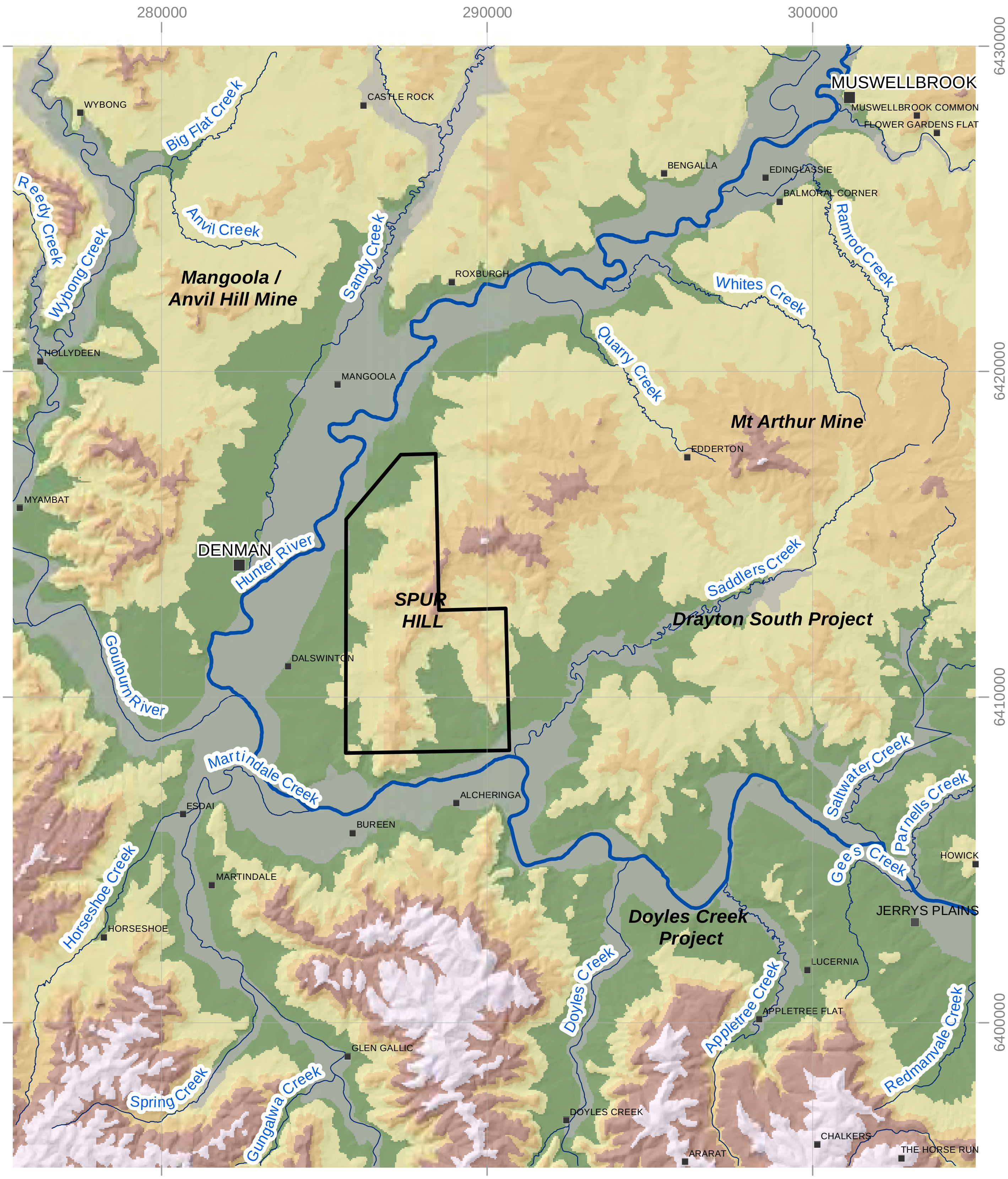
It is clear from the AI Policy that a *risk management* approach should be adopted. That is to say, the level of effort in the assessment should be proportional to the *likelihood* of impacts and the potential *consequences* of those impacts. Other considerations that affect the level of effort are:

- The preliminary groundwater assessment will not have the benefit of information usually provided by associated disciplines (especially surface water hydrology, geochemistry and ecology studies);
- Often the available data for hydrogeological conceptualisation and model calibration would be limited;
- There is a limited 70-90 day window for assessment by the Gateway Panel, who must obtain the advice of the Minister for Primary Industries and the IESC within that period of time; and
- There is to be no public consultation or exhibition of submitted documents.

In combination, the above constraints lead to the conclusion that it would be inappropriate to offer the same level of detail and effort that is normally expended in an Environmental Impact Statement (EIS). Our approach to the modelling for this preliminary groundwater assessment for the Gateway Process is outlined in Table 2.

Table 2 Gateway Process Preliminary Groundwater Assessment - Modelling Approach

Model Feature	Approach
Spatial Scale	Coarse
Temporal Scale	Coarse
Model Extent	30 km x 35 km
Stratigraphy	10 Layers
Spatial Parameter Variability	No
Steady-State Calibration	Yes
Transient Calibration	No (verification only)
Prediction Period	22 years (plus recovery period)
Representation of Fractured Zone	Yes
Tracking of First Workings	No
Sensitivity Analysis	Limited
Uncertainty Analysis	Extensive
Recovery Analysis	Yes
Cumulative Assessment	Law of Superposition
Mitigation Measures	If required
Monitoring Program	Yes
Outputs	Focused on AI Policy
Licensing Volumes	Indicative
Software	MODFLOW-SURFACT
Report	Condensed



Legend

- Town
- Village
- Locality
- Watercourse
- Exploration Lease 7429
- Alluvials

Topography
mAHD

- <150
- 150 - 210
- 211 - 301
- 302 - 430
- 431 - 685

Spur Hill Management
Spur Hill Underground Coal

Figure 1

Project Location

DrawingNo: SHC-002-007
Rev: C.
Created by: CNicol
Date: 16/11/2013.

Scale: 165,000
GDA 1994 MGA Zone 56

0 1 2 4 6 8 km

HYDROSIMULATIONS

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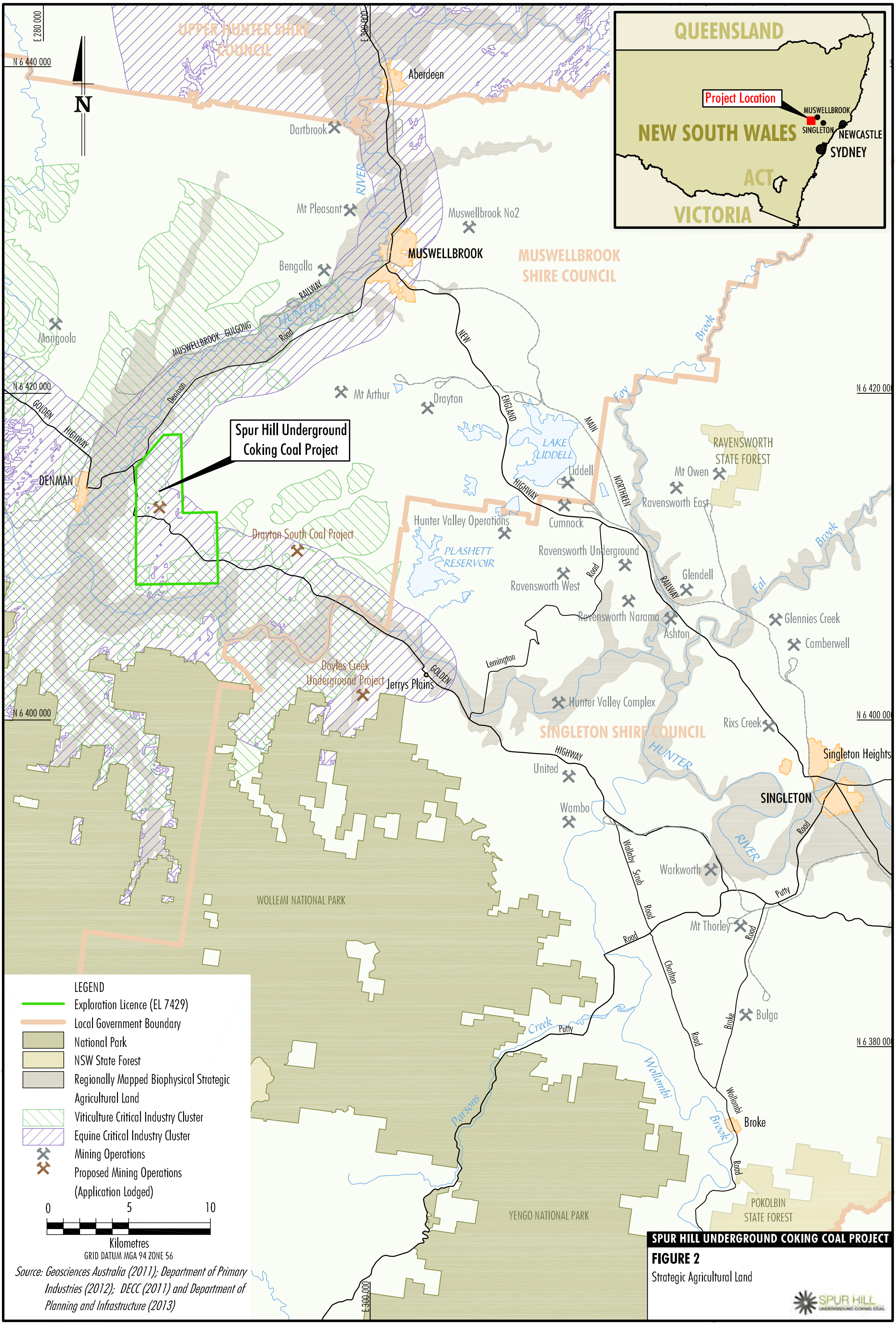


Project Location
QUEENSLAND
NEW SOUTH WALES
MUSWELLBROOK
SINGLETON
NEWCASTLE
SYDNEY
ACT
VICTORIA
UPPER HUNTER SHIRE COUNCIL
MUSWELLBROOK SHIRE COUNCIL
SINGLETON SHIRE COUNCIL
Aberdeen
Dartbrook
Mt Pleasant
Muswellbrook No2
MUSWELLBROOK
Bengalla
Mangoola
Mt Arthur
Drayton
DENMAN
Spur Hill Underground Coking Coal Project
Drayton South Coal Project
Hunter Valley Operations
PLASHETT RESERVOIR
LAKE LIDDELL
Liddell
Cumnock
Ravensworth Underground
Ravensworth West
Ravensworth Narama
Ashton
RAVENSWORTH STATE FOREST
Mt Owen
Ravensworth East
Glendell
Glennies Creek
Camberwell
Doyles Creek Underground Project
Jerrys Plains
Hunter Valley Complex
Rixs Creek
Singleton Heights
SINGLETON
United
Wambo
Warkworth
Mt Thorley
Bulga
Broke
WOLLEMI NATIONAL PARK
YENGO NATIONAL PARK
POKOLBIN STATE FOREST
LEGEND
Exploration Licence (EL 7429)
Local Government Boundary
National Park
NSW State Forest
Regionally Mapped Biophysical Strategic Agricultural Land
Viticulture Critical Industry Cluster
Equine Critical Industry Cluster
Mining Operations
Proposed Mining Operations (Application Lodged)
0 5 10
Kilometres
GRID DATUM MGA 94 ZONE 56
Source: Geosciences Australia (2011); Department of Primary Industries (2012); DECC (2011) and Department of Planning and Infrastructure (2013)
SPUR HILL UNDERGROUND COKING COAL PROJECT
FIGURE 2
Strategic Agricultural Land
SHM-11-01 Gateway_GW_101C

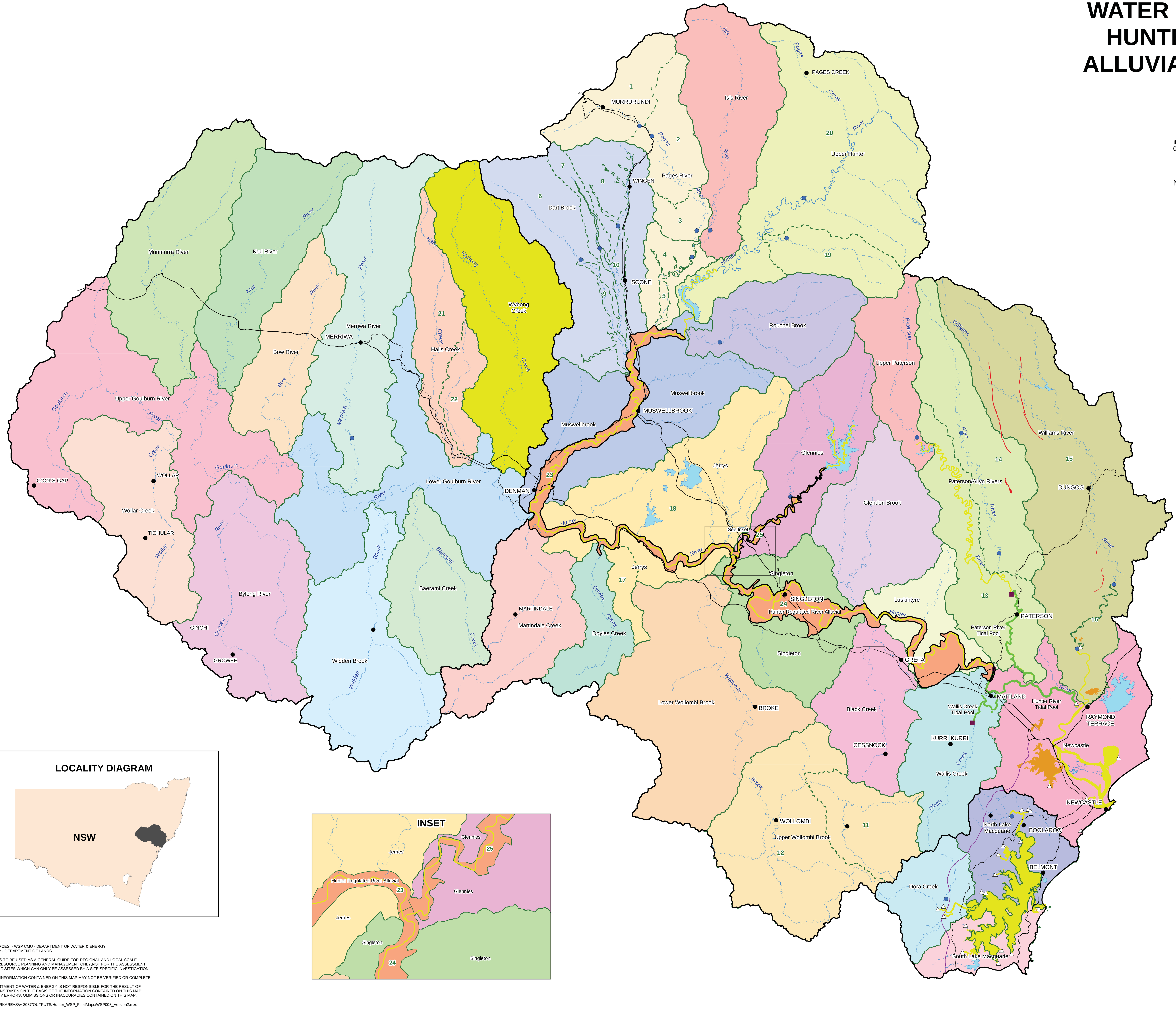
PLAN MAP (WSP003_Version 2)

WATER SHARING PLAN FOR THE HUNTER UNREGULATED AND ALLUVIAL WATER SOURCES 2009

N

0 4.5 9 18 27 36
Kilometres

Note: The area covered by the Wybong Creek, Hunter Regulated River and Paterson Regulated River WSPs are exempt from this plan.



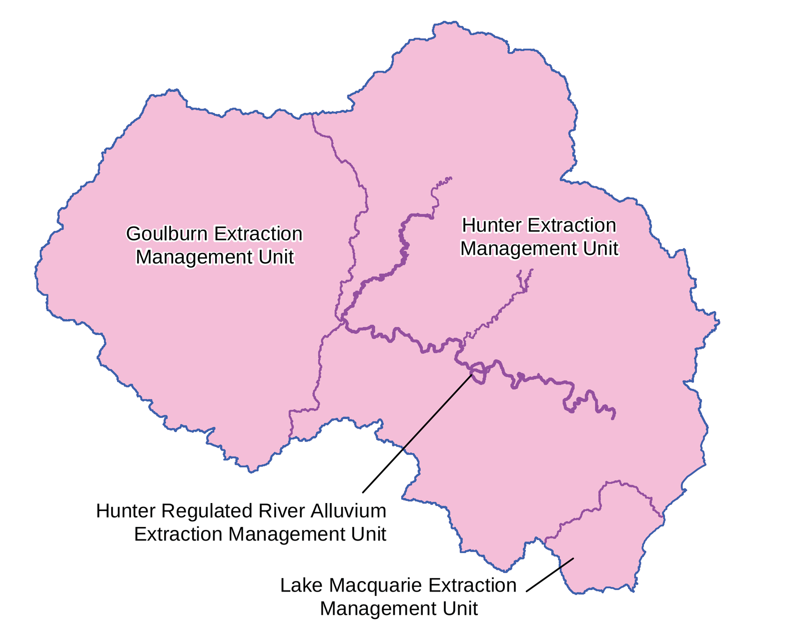
MANAGEMENT ZONE LEGEND
1: Murrurundi Management Zone
2: Scotts Creek Management Zone
3: Kewell Creek Management Zone
4: Gundy Management Zone
5: Segenhoe Management Zone
6: Upper Dart Brook Management Zone
7: Upper Middle Brook Management Zone
8: Petwyn Vale Management Zone
9: Lower Dart Brook Management Zone
10: Lower Middle Brook and Kingdon Ponds Management Zone
11: Congewai Creek Management Zone
12: Wollombi Brook Arm Management Zone
13: Paterson River Tributaries Management Zone
14: Allyn River Management Zone
15: Williams River Management Zone
16: Seaham Weir Management Zone
17: Appletree Flat Management Zone
18: Jerrys Management Zone
19: Stewarts Brook Management Zone
20: Upper Hunter Management Zone
21: Halls Creek Management Zone
22: Giants Creek Management Zone
23: Upstream Glennies Creek Management Zone
24: Downstream Glennies Creek Management Zone
25: Glennies Creek Management Zone

Legend

- Towns
- Limit of plan (Downstream excluded from plan)
- Flow reference point
- Tidal limit
- Highway
- Railway
- Rivers & Creeks
- Tidal Pool Water Source
- Lakes & Dams
- Extraction Management Unit
- Management Zones
- Water Source
- Exemptions from Macro WSP
- Karst GDEs
- Other GDEs

Note:This only includes GDE's within the upland alluvium

EXTRACTION MANAGEMENT UNIT KEY



DATA SOURCES: - WSP CMU - DEPARTMENT OF WATER & ENERGY
CADASTRE: - DEPARTMENT OF LANDS

THIS MAP IS TO BE USED AS A GENERAL GUIDE FOR REGIONAL AND LOCAL SCALE NATURAL RESOURCE PLANNING AND MANAGEMENT ONLY,NOT FOR THE ASSESSMENT OF SPECIFIC SITES WHICH CAN ONLY BE ASSESSED BY A SITE SPECIFIC INVESTIGATION.

THE FIELD INFORMATION CONTAINED ON THIS MAP MAY NOT BE VERIFIED OR COMPLETE.

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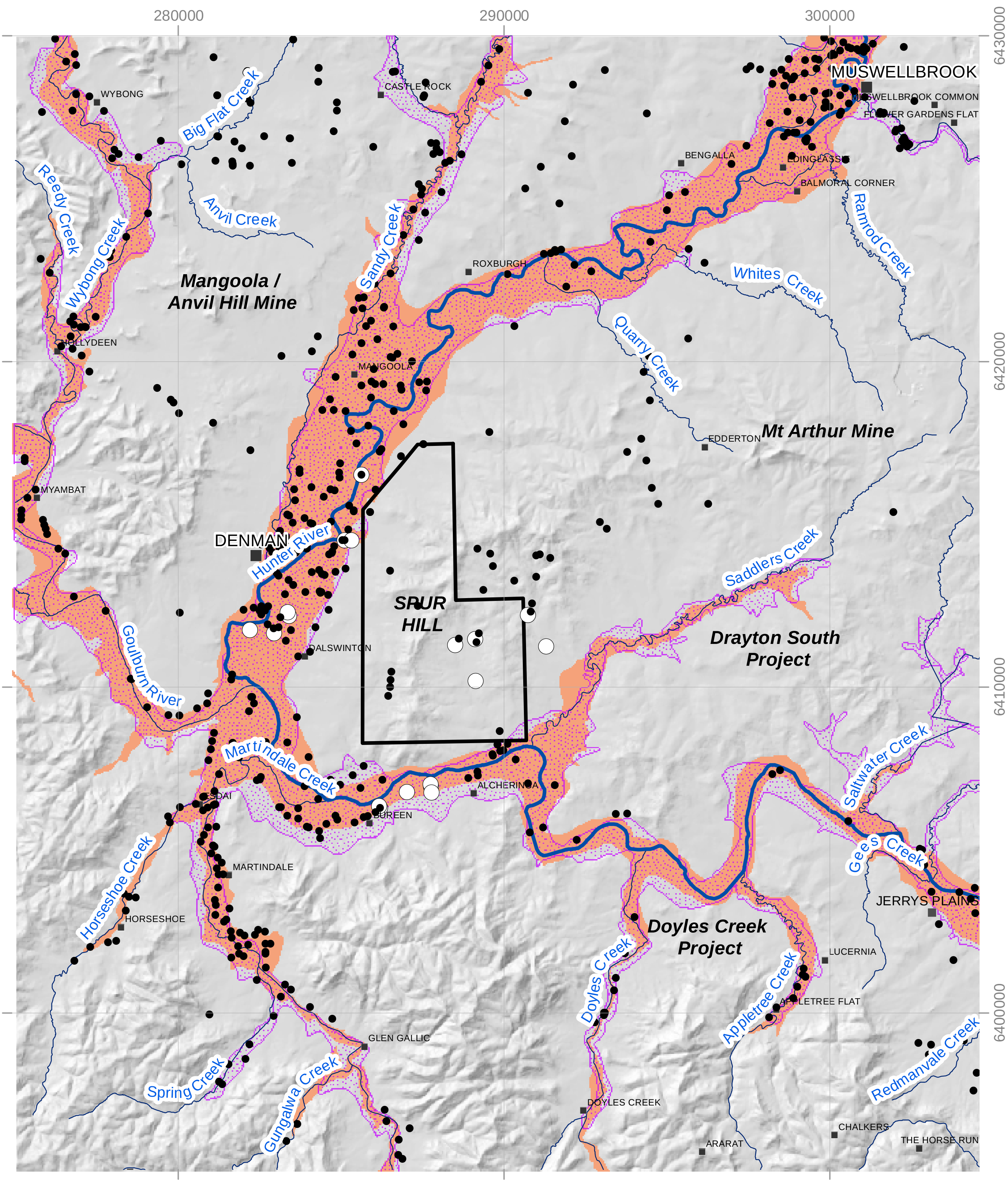

Legend

- NOW Registered Bores
- Census Bores
- Town
- Village
- Locality
- Watercourse
- Exploration Lease 7429
- Alluvials
- Highly Productive Groundwater

Spur Hill Management
Spur Hill Underground Coal

Figure 4

Highly Productive Groundwater

DrawingNo: SHC002-024
Rev: B.
Created by: CNicol
Date: 16/11/2013.

Scale: 165,000
GDA 1994 MGA Zone 56

0 1 2 4 6 8 km

HYDROSIMULATIONS

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2 HYDROGEOLOGICAL SETTING AND CONCEPTUALISATION

This section provides a summary of the Project area hydrogeology, as initiated for this project by Coffey (2013). Some expansion upon and alteration of the work of Coffey (2013) has been included here. The conceptual hydrogeological model adopted by HydroSimulations is also outlined below.

2.1 TOPOGRAPHY

The Project underground mining area and surrounds generally undulates between approximately 100-150 metres (m) Australian Height Datum (AHD) along the major drainage lines, and rises up to approximately 400 mAHD on hills and ridges (Figure 1). Topography is more elevated and variable (more sharply incised) to the south of the Project area, ranging up to nearly 700 mAHD.

2.2 RAINFALL

Rainfall data were obtained for 12 Australian Bureau of Meteorology (BoM) weather stations surrounding the Project. The Decile 5 annual rainfall at each station, as calculated by the BoM, has been used to develop a contour plot of rainfall in the regional area. These stations have a minimum period of record of 41 years, but average 85 years per station. Table 3 lists station information. Contours are shown in Figure 5. Median annual rainfall ranges from more than 720 millimetres (mm) at higher elevations to less than 580 mm in the valley, east of EL7429. Rainfall is topographically controlled, but the variation is small compared to the change in elevation. At EL7429 the median annual rainfall is about 600 mm. The closest station to EL7429 is 61016 (Denman, Palace Street), with 130 years of data coverage.

A rainfall gauge has been recently installed in the Project area by the proponent. The gauge reads hourly rainfall and other weather parameters, however its period of record is too short for statistical analysis. Analysis by Coffey (2013) suggests that there is a good correlation between rainfall on the lease with that recorded at Denman (Station 61016).

The normalised cumulative departure from mean rainfall trend for Denman is presented in Figure 6. These data show that the long-term trend in rainfall in the Upper Hunter Valley comprises a long period of lower than average rainfall between 1900 and 1950, followed by a period of average to moderately higher-than-average rainfall. Comparison with coastal and inland NSW in Figure 6 shows that the latter half of the 20th century was characterised by a more modest rise in rainfall in the Upper Hunter Valley than was experienced in other parts of NSW.

Table 3 Median annual rainfall at 12 Australian Bureau of Meteorology stations in the regional area.

Station Name	Station Number	Median Annual Rainfall (mm)	Easting (mMGA)	Northing (mMGA)	Elevation (mAHD)
Aberdeen (Main Rd)	61000	604	301114	6439270	183
Denman (Palace St)	61016	598	282576	6414151	105
Muswellbrook (Edderton)	61018	566	296216	6413161	168
Muswellbrook (Lower Hill St)	61053	612	300747	6428659	143
Aberdeen (Rossgole)	61065	731	285747	6441764	543
Jerrys Plains Post Office	61086	644	303577	6402525	90
Doyles Creek (Wood Park)	61130	653	293037	6400749	105
Muswellbrook (Lindisfarne)	61168	608	288671	6422468	160
Muswellbrook (Spring Creek, Castle Vale)	61192	658	286663	6434129	259
Baerami Creek (Bronwyn Park)	61204	698	260356	6397323	205
Sandy Hollow (Goulburn Drive)	61235	610	270765	6419791	137
Gungal (Merryfields)	61324	649	265685	6429682	182

MGA – Map Grid of Australia 1994.

2.3 EVAPORATION

The closest climate stations within 100 km of the site with reasonable amounts of pan evaporation data are Scone SCS (Station 61089, 28 km to the northeast, elevation 216 mAHD, with 43 years of data between 1965 and 2013) and Lostock Dam (Station 61288, 68 km to the east, elevation 200 mAHD, with 40 years of data between 1969 and 2013).

Table 4 lists the average monthly pan evaporation for the sites, and the monthly Decile 5 rainfall for Denman (Station 61016) over the period 1863 to 2013 (note that the annual values are not the same as the sum of the monthly values).

Both rainfall and evaporation follow a simple sinusoidal trend which is a maximum in January and December, with virtually no lag between trends. A rainfall deficit occurs for all months of the year (for median rainfall), using either evaporation station data. Pan evaporation is about three times greater than rainfall during the summer months and about two times greater during the winter months, indicating a semi-arid climate.

Table 4 Average pan evaporation and median rainfall

Month	Median Monthly Rainfall at Denman (Station 61016) (mm)	Average Monthly Pan Evaporation (mm)	
		Scone SCS (Station 61089)	Lostock Dam (Station 61288)
January	61	220	189
February	47	175	144
March	37	155	127
April	31	105	99
May	27	68	78
June	32	48	66
July	30	56	78
August	27	84	109
September	32	117	141
October	40	155	167
November	50	183	174
December	57	220	208
ANNUAL	598	1607	1571
Number of Years	130*	43	40
Start Year	1883	1965	1970
End Year	2013	2013	2013
Elevation (mAHD)	105	216	200

Note: Annual values are not the same as the sum of the monthly values.
* Years open.

The annual average Area Actual Evapotranspiration shown on BoM mapping is approximately 650 mm at Spur Hill. The BoM defines Area Actual Evapotranspiration as that evapotranspiration that actually takes place, under the condition of existing water supply, from an area so large that the effects of any upwind boundary transitions are negligible and local variations are integrated to an areal average.

2.4 SURFACE DRAINAGE

The area is drained by the Hunter River, which is perennial and flows from northeast to southwest in the vicinity of the Project before swinging eastward to the south of EL7429 (Figure 1). The Goulburn River is the largest tributary, with its confluence with the Hunter River being west of EL7429. Saddlers Creek is a small tributary that drains the area to the east of EL7429, its confluence with the Hunter River being at the southeastern lease corner.

The nearest stream flow gauging stations to the site are listed in Table 5 and current stations are shown in Figure 7. Stream flow exceedance statistics for the 1993 period for the Hunter River gauges are presented in Figure 8. This shows that flows are broadly similar between Muswellbrook and Denman, but are generally lower at lower flows (and higher at higher flows) downstream at Liddell.

Table 5 Stream Flow Gauging Stations

Gauge Number	210002	210055	210083	210031	210043
Gauge Name	Hunter River at Muswellbrook Bridge	Hunter River at Denman	Hunter River at Liddell	Goulburn River at Sandy Hollow	Saddlers Creek at Bowfield
Catchment Area (km^2)	4220	4530	13400	6810	78
Easting (MGA)	301170	284705	304905	271713	292813
Northing (MGA)	6429172	6415039	6403439	6418714	6410996
Distance from site centre	22 km northeast	4 km northwest	19 km southeast	18 km northwest	5 km east
Average Flow (1970 to 2010) (ML/day)	769	710	1132	408	3.2^
Zero gauge elevation (mAHD)	136.25	102.99	60.96	113.45	-
Average river stage (1970 to 2010) (m)	0.98	0.54	5.37	1.52	-
Average river stage elevation (1970 to 2010) (mAHD)	137.23	103.53	66.33	115.00	-

^ For the period 25/01/1956 to 31/10/1981.
km^2 – square kilometres.
ML/day – megalitres per day.

2.5 GEOLOGY

The site is located in the Hunter Coalfield of NSW, a region of the Sydney Basin. The geology comprises interbedded sandstones, siltstones, and coal seams of the Wittingham Coal Measures and Newcastle Coal Measures. The geology is shown in Figure 9 and the stratigraphy is shown in Figure 10. The Wittingham Coal measures in this area are overlain by what were once known as the Wollombi Coal Measures but which are now classified as the Newcastle Coal Measures. Sill and dyke intrusions have been identified from surface mapping, explorative drilling and aerial geophysical surveys.

Apart from the coal measures, significant tracts of alluvium are present over most of the reach of the Hunter River in this area. The alluvium consists of fine-grained unconsolidated sediments overlying medium to coarse gravels at the base. Alluvial thickness may reach up to 30 m or more, near the river channel (Environment and Natural Resource Solutions, 2012; Groundwater Imaging, 2012; Coffey, 2013).

The dominant known geological structure is the Denman Anticline with fault zones on the edges. The north-trending Mount Ogilvie Fault separates the Newcastle Coal Measures to the west from the older Wittingham Coal Measures to the east (see Figure 9). The strata to the west of the fault are downthrown by more than 100 m, and dip to the northwest by 2 to 5 degrees. The fault plane appears to be almost vertical on a cross section of the Hunter Coalfield 1:100,000 Geology Map. It is understood that the SHM site geologists regard the Mount Ogilvie Fault as a monocline with some associated faulting (an interpretation supported by seismic information), with continuity of the coal seams rather than a major truncation and throw of the seams.

Proposed mining operations target the Whynot, Bowfield, and Warkworth Seams (primarily the Whynot and the Warkworth Seams). These seams occur towards the top of the Jerrys Plains Subgroup in the Wittingham Coal Measures.

2.6 GROUNDWATER FLOW SYSTEMS

There are two major HSUs within the study area:

- Hunter Alluvium. An alluvial aquifer associated with the Hunter River. It comprises silt underlain by gravel, reaching a thickness of 30 m or more near the Hunter River channel. The Hunter Alluvium is classified as a highly productive groundwater source; and
- Sydney Basin Permian rock units, classified by NOW as a porous rock aquifer of low resource potential. It should be noted however that flow through fracture networks also occurs. This aquifer is associated with the Newcastle and Wittingham Coal Measures, which comprise interlayered sandstone, siltstone, and coal seams to significant depth. The coal seams typically form the more permeable sub-units, whilst the interbeds form lower permeability resistors to groundwater flow.

Groundwater is likely to flow between these two HSUs, although inter-aquifer flow rates are likely limited by the strongly contrasting permeability differences between the two units; i.e. the majority of groundwater flowing through the alluvium is likely to have been derived from rainfall recharge and river leakage directly into the alluvials, and is likely to primarily discharge out of the alluvium directly. Groundwater flows through the porous rock aquifer, and discharges via the alluvium, creeks and evapotranspiration, at significantly slower rates than in the far more permeable Hunter Alluvium.

Coffey (2013) generated potentiometric surface mapping for the Glen Munro and Arrowfield Seams in EL7429 (Figure 11). Both of these indicate a potentiometric divide around bore SHD010, to the north and south of which groundwater flows to the north-northwest and south-southeast respectively. This regime appears to be controlled by the primary discharge boundary of the Hunter River and/or its alluvium, which wraps around the northwestern lease boundary, southward along the western boundary, before swinging eastward along the southern boundary.

Harrison (1946) provides an early interpolated watertable for the Hunter alluvium surrounding the site (Figure 12). Alluvial groundwater flows along the line of the river from the north to the southeast. In most cases, inflection of the potentiometric contours around the Hunter River in Figure 12 (indicating a convex surface) suggests that the river acts as a source of water to the alluvium. The potentiometric surface is unlikely to have changed significantly since that time, due to the presence of the river and its surrounding incised land surface, which no doubt form the primary control on groundwater recharge and/or discharge, and hence on groundwater flow directions and heads.

Coffey (2013) also generated a hydraulic head cross section for January 2013 across EL7429 using vibrating wire piezometer data collected for the Project (see Figure 13). Hydraulic heads are characterised by small horizontal and vertical gradients, suggesting little impact from mining operations to the north and northeast (Mangoola/Anvil Hill and Mount Arthur mines). Discharge is to the Hunter River and/or alluvium, even from depths as great as 400 m. Given the small vertical hydraulic gradients and the likely vertical anisotropy of the Coal Measures, groundwater flux is likely to be predominantly in the lateral direction, but this will change significantly with mining in the areas of strata above active mining.

2.6.1 Groundwater Use

Figure 7 shows the groundwater bores registered on NOW's database. There are 595 registered groundwater bores within the Project area and surrounds. The 18 bores that were surveyed by Groundwater Exploration Services (GES) (2013) for the Project bore census are also shown in Figure 7. Most of the groundwater usage in the area is clearly from the Hunter Alluvium. Comparatively few registered bores exist in the Permian porous rock aquifer, likely due to its lower yield and poorer water quality.

2.6.2 Groundwater Quality

Groundwater quality data for the study area, in the form of electrical conductivity (EC), are summarised in Figure 14. These data were sourced from publicly available reports for surrounding mines (Mackie Environmental Research [MER], 2006; MER, 2007; Australasian Groundwater and Environmental Consultants [AGE], 2012; AGE, 2013). The data suggest that groundwater in the Permian coal measures is generally more saline than that in the alluvium. EC data for the Hunter Alluvium reported by Coffey (2013; 4900-6490 microSiemens per centimetre [uS/cm]) are in agreement with the ranges shown in Figure 14.

Groundwater EC data collected for this Project's bore census (GES, 2013) indicates an average Hunter Alluvium EC of 1187 uS/cm on the floodplain (based on 11 samples), and 4570 uS/cm on the colluvial slopes (i.e. more distal to the river; based on 3 samples). This suggests that the higher "alluvial" EC data from surrounding mines' reports summarised in Figure 14 are likely dominated by samples either from smaller streams' alluvial deposits, and/or from the alluvials and/or colluvials located further from the Hunter River than those collected for this Project's bore census. A general pattern of freshening EC in the alluvium towards the Hunter River was observed during the bore census (*pers. comm*. Andrew Fulton (GES), May 2013). This suggests that the Hunter River is a significant source of water to the Hunter Alluvium, particularly in the alluvial deposits nearest the river.

Kellett *et al*. (1989) used geochemical analysis to investigate the origins of solutes in groundwater in the Upper Hunter Valley. They found that the high salinity of groundwater in the Permian porous rock unit is of connate (Permian marine) origin, with further solute input from the oxidation of sulphides in coal seams. They also found that porous rock groundwater discharges up into the Hunter Alluvium, where it mixes with water derived from leakage from the Hunter River, and that the rock-derived salts accumulate in the groundwater sinks (i.e. due to evapotranspiration) around the margins of the Hunter Alluvium.

Kellett *et al*. (1989) also concluded that groundwater discharge up from the Permian porous rock unit (Wittingham Coal Measures) around the Mt Ogilvie Fault at Alcheringa (immediately south of EL7429; Figure 9) is strong enough to have over-printed the geochemical signature of the Hunter River as the dominant water source within alluvial groundwater at this location. This suggests that:

- The vertical permeability of the fault is higher than the lateral permeability of the alluvium at this location; and/or
- There is a groundwater sink in the Hunter Alluvium at this location, the likely candidate being evapotranspiration of shallow groundwater. This sink could be generating a build-up of salts derived from Wittingham Coal Measures groundwater discharging upwards into the alluvials via the Mt Ogilvie Fault.

The authors also noted strong upwelling of saline groundwater from the Wittingham Coal Measures at the northern end of the Mt Ogilvie Fault (beyond the northern extent of the Project area).

2.6.3 Hydraulic Properties

Figure 7 shows the locations of drill core sampling and testing sites, and packer testing sites, collected and conducted for the Project. These analyses are detailed by GES (2013). Coffey (2013) presented and analysed a range of hydraulic conductivity and porosity data, which are summarised and expanded upon here.

Hydraulic Conductivity (K)

Alluvial hydraulic conductivity has not been measured at the site, however long-term pumping tests conducted at other mines along similar reaches of the Hunter River indicate lateral conductivities ranging between 5 and 320 m/day within the gravels.

The currently available hydraulic conductivity data are summarised in Figure 15. Figure 15 shows that there is a large downward shift in measured horizontal core permeabilities compared to the values derived from packer tests. This is not uncommon and is expected because packer tests measure the (local-scale) fracture permeability whilst the core data measure the host rock mass (unfractured) permeability.

The core data set provides a useful lower bound on hydraulic conductivity. Horizontal conductivity from the Project investigations ranges from 2E-7 m/day to 1E-3 m/day for the interburden, and from 1E-4 m/day to 0.02 m/day for the coal seams. There is a broad trend of decreasing matrix permeability with depth of overlying strata observed in the core data, although little observable trend in the Project packer test data.

Vertical hydraulic conductivity of the rock matrix based on core data ranges from 1E-7 m/day to 3E-5 m/day. Observed horizontal to vertical hydraulic conductivity ratios range from 3 to 56 with a median of 11, defined using the arithmetic mean horizontal conductivity divided by the harmonic mean vertical hydraulic conductivity.

The largest mapped geological structure in the Project area, the Mt Ogilvie fault, is not considered a major hydraulic barrier or conduit to groundwater flow, based on local scale geological modelling and interpretation of exploration data by site geologists. The geologists' interpretation for the lease area is that the coal measures "roll over" the structure, rather than have become displaced by it. However, exploration core inspection suggests localised areas of slightly greater vertical fracturing around the Mt Ogilvie structure.

Dykes present within the coal measures are thought to locally enhance hydraulic conductivity along their upper and lower altered and fractured margins, but this is thought to be limited to a very local scale effect, based on core data inspection. The main dyke rock mass appears to be highly impermeable, and hence further consideration of the localised high permeability around the dyke margins is not warranted in the Project modelling.

Specific Yield (Sy)

Specific yield (together with porosity and specific storage) usually decreases with depth. Specific yields for Sydney Basin sedimentary strata in the context of drainage due to longwall subsidence generally vary between 0.005 and 0.01. The Hunter Alluvium is expected to possess a specific yield in the range of 0.05 – 0.2.

Specific Storage (Ss)

Direct testing data are not generally available for specific storage (Ss) of coal seams or interburden. The specific storage of Hawkesbury Sandstone in the Blue Mountains west of Sydney has been estimated to be about 1E-6 m^{-1} (Kelly et al., 2005) in the upper zones where fracture flow is dominant. Results of long duration pumping tests in Hawkesbury Sandstone in western Sydney (Tammetta and Hawkes, 2009) indicated an average specific storage of 1.5E-6 m^{-1} for depths between ground surface and 300 m.

Assuming that the total primary and secondary porosity that allows fluid flow ranges between 10% at the surface and 5% at depth, and assuming that the aquifer is incompressible, then the specific storage minima could range between 4.5E-7 m^{-1} at the surface to 2.3E-7 m^{-1} at depth (field measurements of specific storage show its depth variability; see for example Heywood, 1997). Greater aquifer compression is possible at shallower depths, where flow through defects predominates, than at deeper depths.

Good estimates of specific storage can also be made based on Young's Modulus and porosity. For coal, Ss generally lies in the range 5E-6 m^{-1} to 5E-5 m^{-1}, and interburden is generally slightly higher than this due to the greater porosity (Mackie, 2009). Surrounding mines' model calibration parameterisations suggest that Ss is in the order of 1E-4 m^{-1} for the coal seams (slightly higher than Mackie's estimates), and 1E-6 m^{-1} for interburden (slightly lower than Mackie's estimates). The values used in this study were generally 2E-4 m^{-1} for the coal seams, 1E-6 m^{-1} for interburden, and 1E-7 m^{-1} for underburden.

2.6.4 Groundwater-Surface Water Interaction

Figure 16 displays the gauged monthly flow loss and gain statistics between Muswellbrook and Denman. This shows that the river generally loses water along this reach (averaging around 31 ML/day), with the exception of June through August, and to a small degree February. The largest losses occur over spring through autumn, and are no doubt in part related to surface water diversions for agricultural use (approximately 2ML/day; Coffey, 2013), but also imply that the river loses water down into the underlying Hunter Alluvium, given the very small rare gains and larger and more consistent losses. This inference is strengthened by the fact that the estimated flow losses are underestimates due to a lack of accounting for inflows from several ungauged tributaries along this reach. There are no licensed groundwater extractions from the alluvium along the Hunter River between Muswellbrook and Denman (Coffey, 2013), and hence unaccounted for groundwater usage impacts on stream flows are not expected to compromise this water balance analysis.

Figure 17 presents similar monthly statistics for the Hunter River between Muswellbrook and Liddell. The uncertainties of this analysis are larger than those for the Muswellbrook to Denman analysis, given the greater number of ungauged tributaries and their larger catchment areas, inflows from which have not been accounted for. Regardless, these data also suggest that on average, for most of the time, the Hunter River loses significant volumes of water into the underlying alluvium along this reach.

Hydrometric analysis of groundwater-surface water interaction was undertaken using groundwater levels in NOW bore GW080077 and Hunter River stage elevations at the Denman gauge (#210055). The location of these sites is shown in Figure 7, and the analysis is presented in Figure 18. River water levels are consistently approximately 2 m or more higher than adjacent groundwater levels, indicating a downward potential for river water to migrate into the Hunter Alluvium at this location. The comparison of alluvial and Permian rock groundwater EC against Hunter River EC also suggests that the river is the dominant source of water in Hunter Alluvium at this location. This analysis strongly supports the conclusions of other studies (Kellett *et al.*, 1989), and of the reach-scale mass balances outlined above, that the Hunter River is a losing stream in the Project area.

It should be noted that the baseflow analyses of Coffey (2013) provide a qualitative and subjective estimate of baseflow, primarily along the Hunter River upstream of Muswellbrook because the majority of gauged flows, even as far down catchment as Liddell, are primarily derived from this up-catchment area. This is clearly indicated via the analyses shown in Figure 8, Figure 16 and Figure 17 and discussed above, which strongly suggest net losing conditions along the Hunter River between Muswellbrook and Liddell (i.e. the area of interest to the Project).

2.7 CONCEPTUAL HYDROGEOLOGICAL MODEL

2.7.1 Recharge

Recharge to the Hunter Alluvium is predominantly derived from leakage from the Hunter River into the alluvials, and from rainfall recharge and irrigation onto the alluvials. Hydrograph fluctuation analysis of NOW bore GW080077 suggests maximum recharge rates to the alluvium of approximately 100 mm/year, but more typically around 30 mm/year, assuming a specific yield of 0.1 and maximum / typical watertable fluctuations of 1 m / 0.3 m, respectively. Some recharge to the alluvials also occurs from the underlying and adjacent Permian porous rock aquifer, as indicated by EC data and other geochemical data (see Section 2.6.2 and Kellett *et al*., 1989). The dominant alluvial aquifer recharge source is however leakage from the Hunter River.

Recharge to the Permian porous rock aquifer is significantly lower than that to the alluvials because of its inherently lower capacity to receive and transmit water due to its significantly lower hydraulic conductivity and storage properties. The higher EC of the porous rock aquifer compared to that of the alluvials supports this conclusion. The vibrating wire piezometer data (presented in Attachment C; see “SH” series bores) shows no observable response to seasonal recharge events. Hence seasonal recharge to the porous rock is expected to be close to zero – probably less than 5 mm/year.

2.7.2 Discharge

Discharge from the Permian porous rock aquifer is primarily to the Hunter Alluvium (see the discussion at the beginning of Section 2.6), but also to evapotranspiration from shallow groundwater in lower lying areas where the porous rock is at outcrop. Discharge from the Hunter Alluvium is primarily via groundwater usage and evapotranspiration from shallow watertable areas.

Current hydraulic heads in the coal measures show minimal vertical or horizontal gradients. Drawdown from neighbouring mines to the north and east does not appear to have significantly impacted the site. With Project mining, significant vertical gradients will be created, and groundwater discharge into the mine will become a significant discharge component of the water balance.

2.7.3 Hydraulic Properties

Hydraulic conductivity measurements from the site indicate that the sample of measurements may be regarded as part of the population of measurements for the Hunter Valley. If so, hydraulic conductivity in undisturbed coal measures will decrease with depth.

Gravels at the base of the alluvium at the site are expected to have a relatively high lateral conductivity. The vertical leakance between the alluvium and coal measures is ***not*** considered a crucial parameter for analysis of reduction in discharge to the alluvium – the reason being that there are no other significant discharge pathways in this area for mining activities to impact upon, and hence vertical leakance will only appreciably affect the timing, not the magnitude, of impacts upon this component of the flow system.

The Mt Ogilvie structure is ***not*** considered to form a lateral barrier to groundwater flow, based upon the site geologists' interpretation of this structure as a roll-over feature, rather than a fault across which the coal measures have been vertically displaced and truncated. The feature appears to provide at least localised pathways for vertical groundwater flux from the Wittingham Coal Measures up to the land surface (see Kellett *et al*., 1989).

2.7.4 Impact of Mining on Overlying Strata

The impact of mining on the permeability of caved overlying strata has been based on experience of monitoring and groundwater modelling gained to date, in other locations, combined with the most recent research available for subsidence impacts on aquifer materials.

It is generally accepted in literature that there will be a sequence of deformational zones (Figure 19) usually described as:

- the caved zone;
- the fractured zone, consisting of:
  - a lower zone of connective-cracking; and
  - an upper zone of disconnected-cracking;
- the constrained zone; and
- the surface zone.

The rocks in the connective-cracking part of the fractured zone will have a substantially higher vertical permeability than the undisturbed host rocks. This will encourage groundwater to move out of rock storage downwards towards the goaf. In the upper part of the fractured zone, where disconnected-cracking occurs, the vertical movement of groundwater should not be significantly greater than under natural conditions.

Depending on the width of the longwall panels and the depth of mining, and the presence of low permeability lithologies, there will be a constrained zone in the overburden that acts as a bridge. Rock layers are likely to sag without breaking, and bedding planes are likely to open. As a result, some increase in horizontal permeability can be expected.

In the surface zone, near-surface fracturing can occur due to horizontal tension at the edges of a subsidence trough. Fracturing will be shallow (<20 m), often transitory, and any loss of water into the cracks will not continue downwards towards the goaf.

The strata movements and deformation that accompany subsidence will alter the hydraulic and storage characteristics of aquifers and aquitards. As there will be an overall increase in rock permeability, groundwater levels will be reduced either due to actual drainage of water into the goaf or by a flattening of the hydraulic gradient without drainage of water (in accordance with Darcy's Law).

At the base of the fractured zone, groundwater pressures will reduce towards atmospheric pressure.

Mine Subsidence Engineering Consultants (MSEC) (2009) conducted a literature review of reported "fractured zone" heights in NSW coal mines, including the combined height of connective and disconnected-cracking. Analysis of the literature values shows that the median height is 0.6 times the longwall panel width. This study has adopted 0.6 as the ratio for estimating the height of the connective-cracking zone. As the reported heights were a mixture of connective-cracking heights and disconnected-cracking heights, adoption of this ratio is a conservative approach. It is noted that adoption of the Forster (1995) prediction methodology (Figure 19) would result in a height of connective-cracking of between 66 and 116 m. More detail on the implementation of the fractured zone in the numerical model is provided in Section 3.5.

The EIS Groundwater Assessment would include further investigations into the height of connective-cracking including consideration of other prediction techniques and review of recorded values in literature.

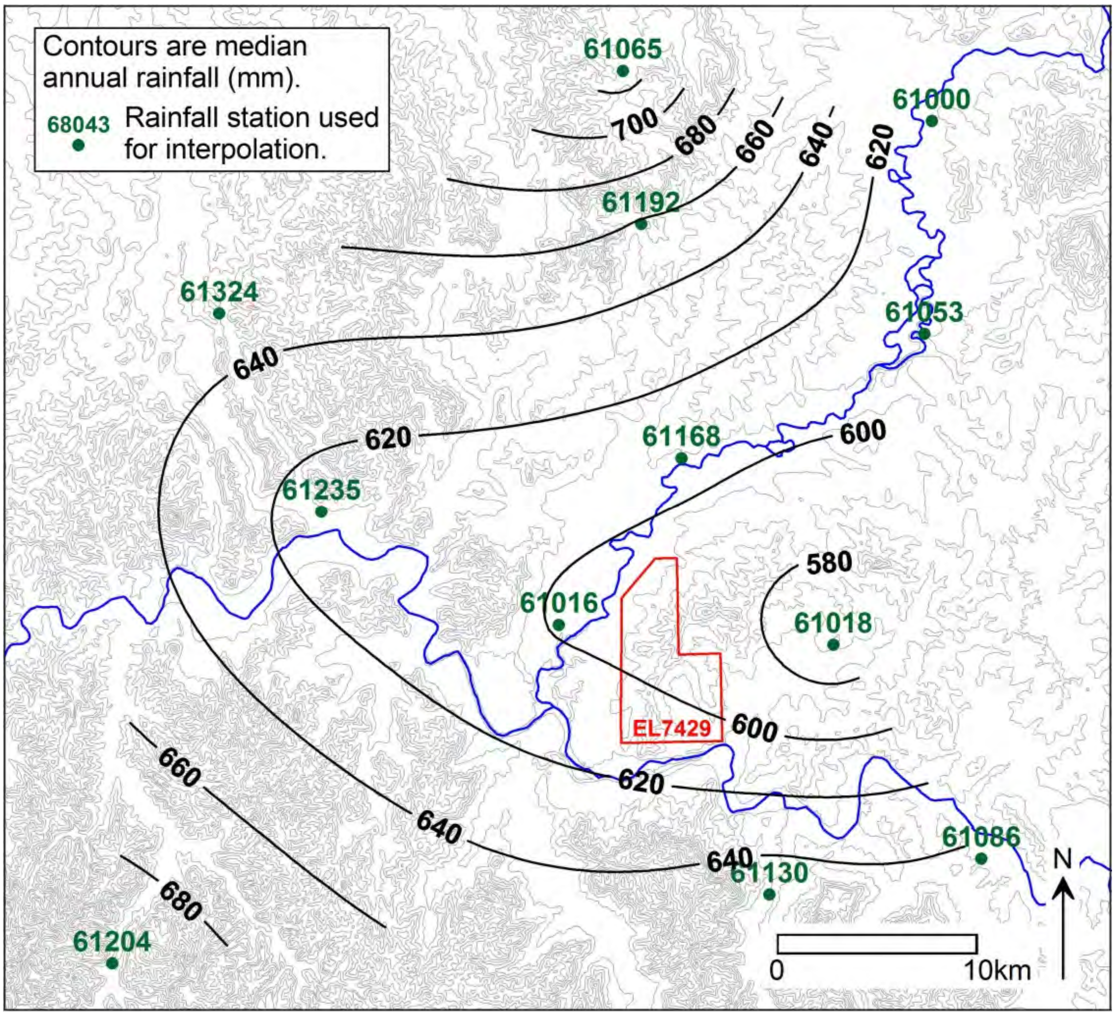


Figure 5 Median Annual Rainfall

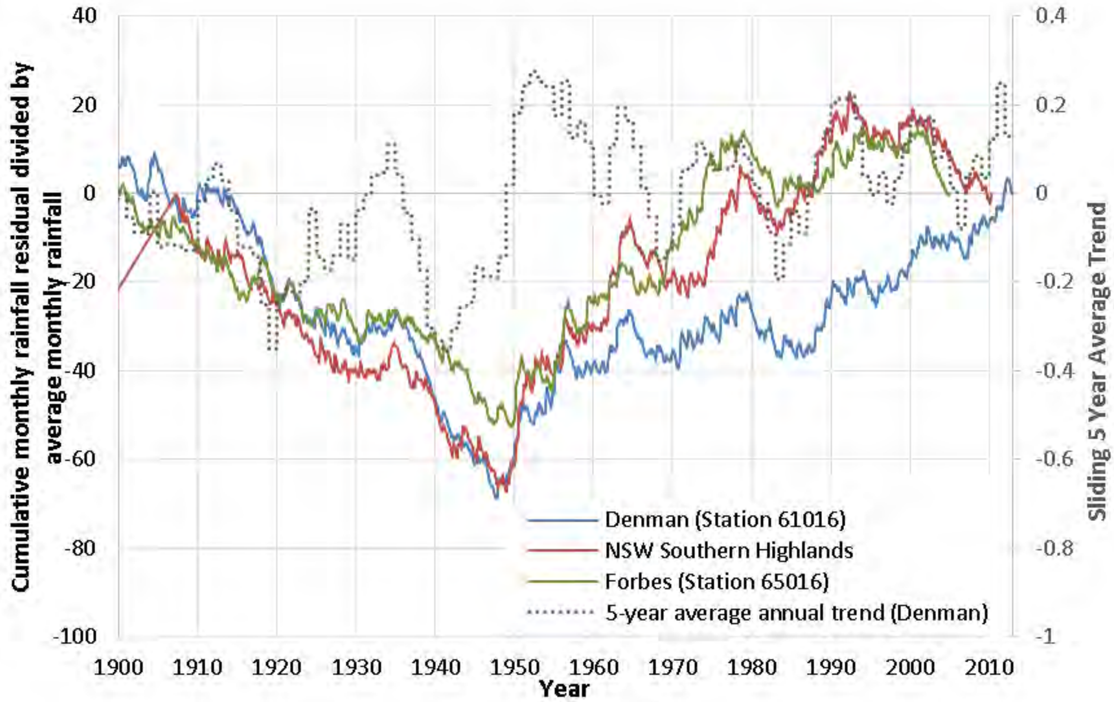
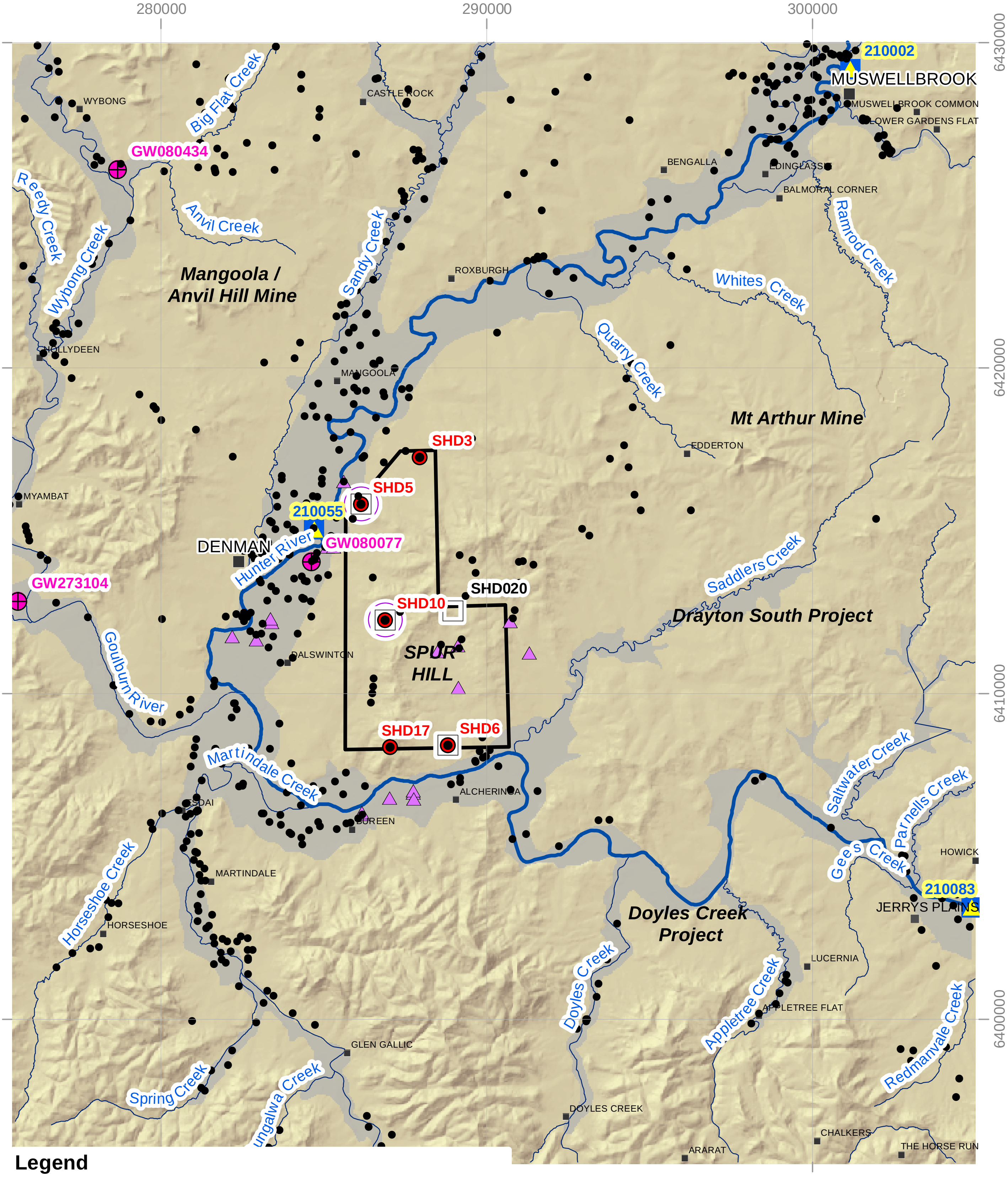


Figure 6 Cumulative Departure from Mean Rainfall Trends



Legend

- Town
- Village
- Locality
- Flow Gauge
- NOW Monitoring Bore
- Spur Hill Bore Census
- Spur Hill Vibrating Wire Piezometers
- Core Tests
- Packer Tests
- NOW Registered Bores
- Watercourse
- Exploration Lease 7429
- Alluvials

Spur Hill Management
Spur Hill Underground Coal

Figure 7

Monitoring and Data Locations

DrawingNo: SHC002-018
Rev: D.
Created by: CNicol
Date: 16/11/2013.

Scale: 165,000
GDA 1994 MGA Zone 56

0 1 2 4 6 8 km

HYDROSIMULATIONS

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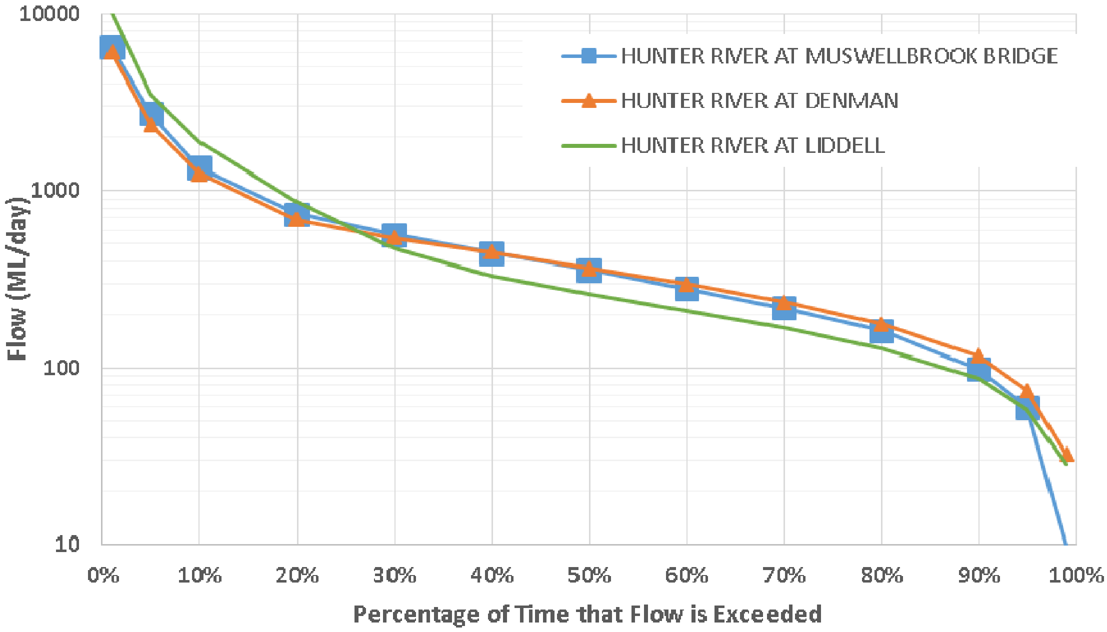
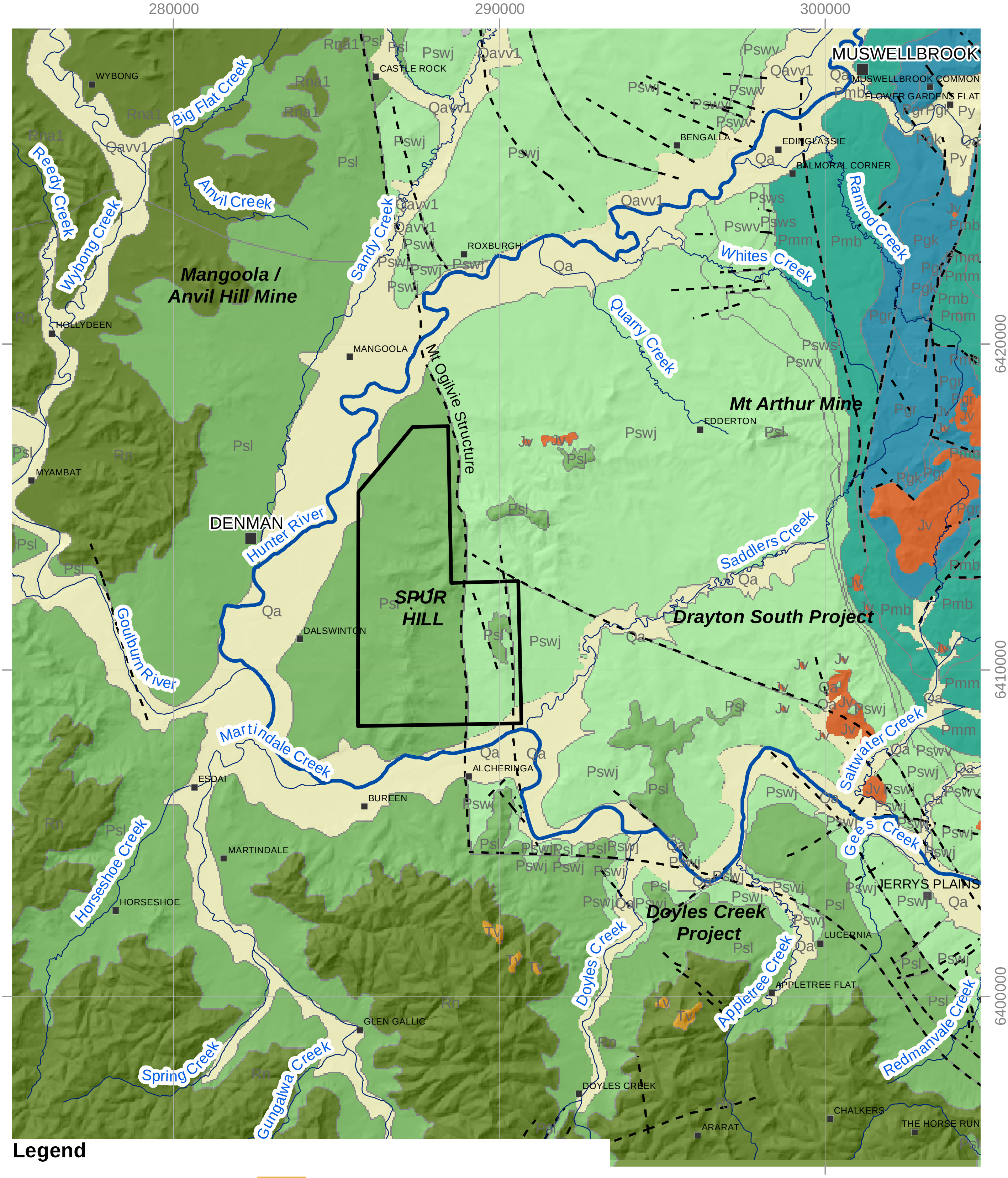


Figure 8 Stream Flow Exceedance Curves for the Hunter River (1993-2013)



Legend

- Town
- Village
- Locality
- Watercourse
- Exploration Lease 7429
- Geological Structures

Geological outcrop (250k)

- Quaternary Alluvium
- Tertiary Basalts
- Narrabeen Group (Triassic)
- Jurassic Basalts
- Newcastle Coal Measures (Permian)
- Wittingham Coal Measures (Permian)
- Maitland Group (Permian)
- Greta Coal Measures (Permian)
- Undifferentiated Palaeozoic / Mesozoic

Spur Hill Management
Spur Hill Underground Coal

Figure 9

Geological Outcrop

DrawingNo: SHC002-012
Rev: B.
Created by: CNicol
Date: 16/11/2013.

Scale: 165,000
GDA 1994 MGA Zone 56

0 1 2 4 6 8 km

HYDROSIMULATIONS

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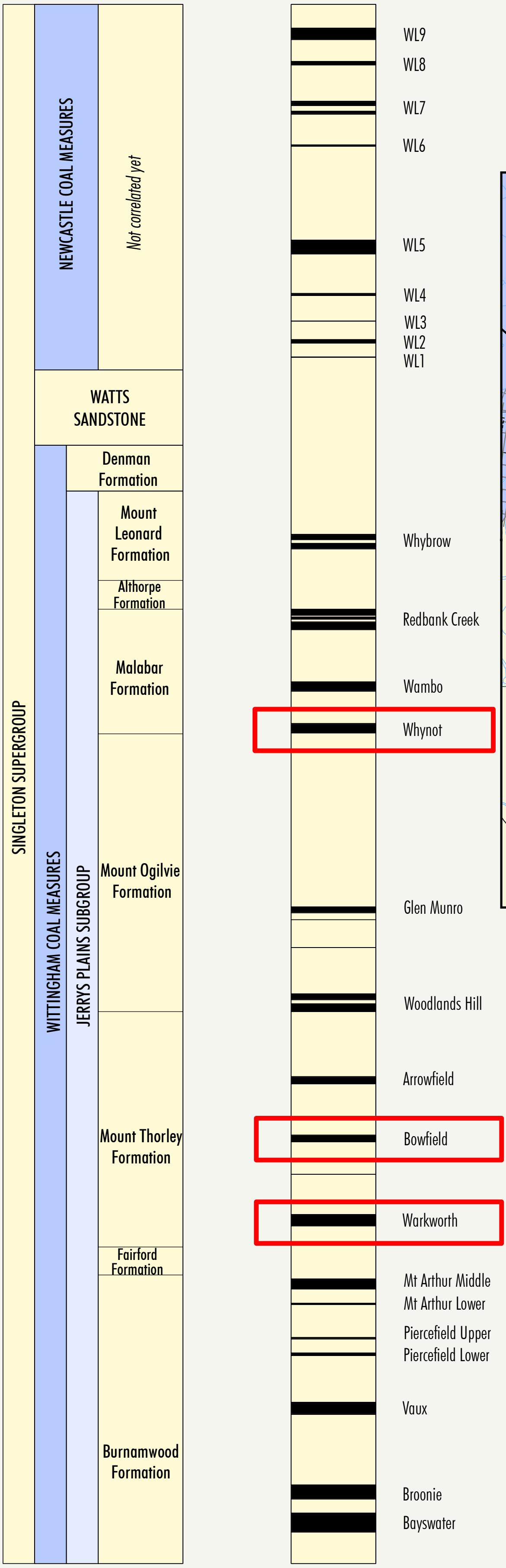
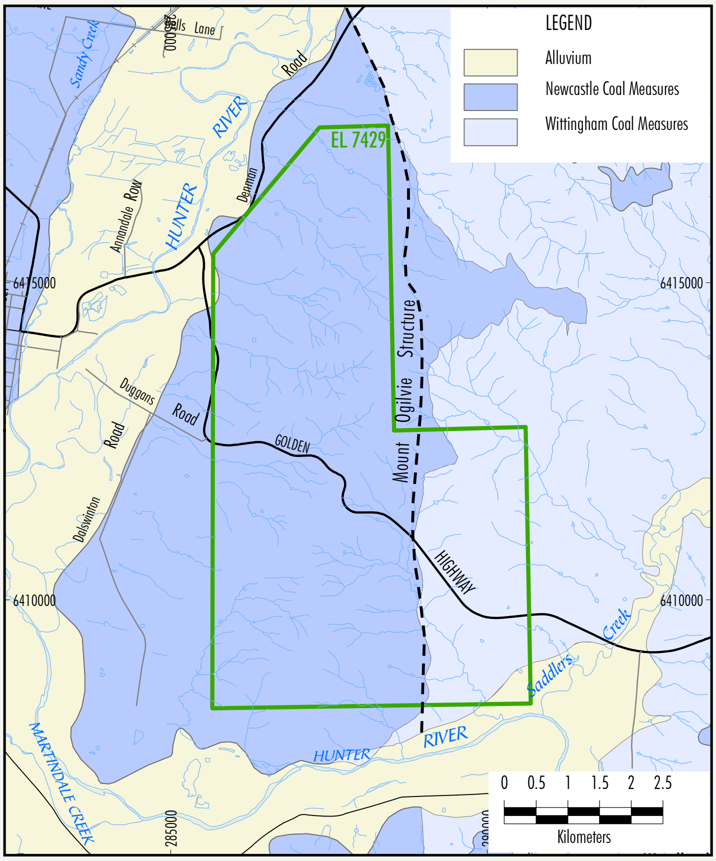


Note: Mined seams shown in red boxes

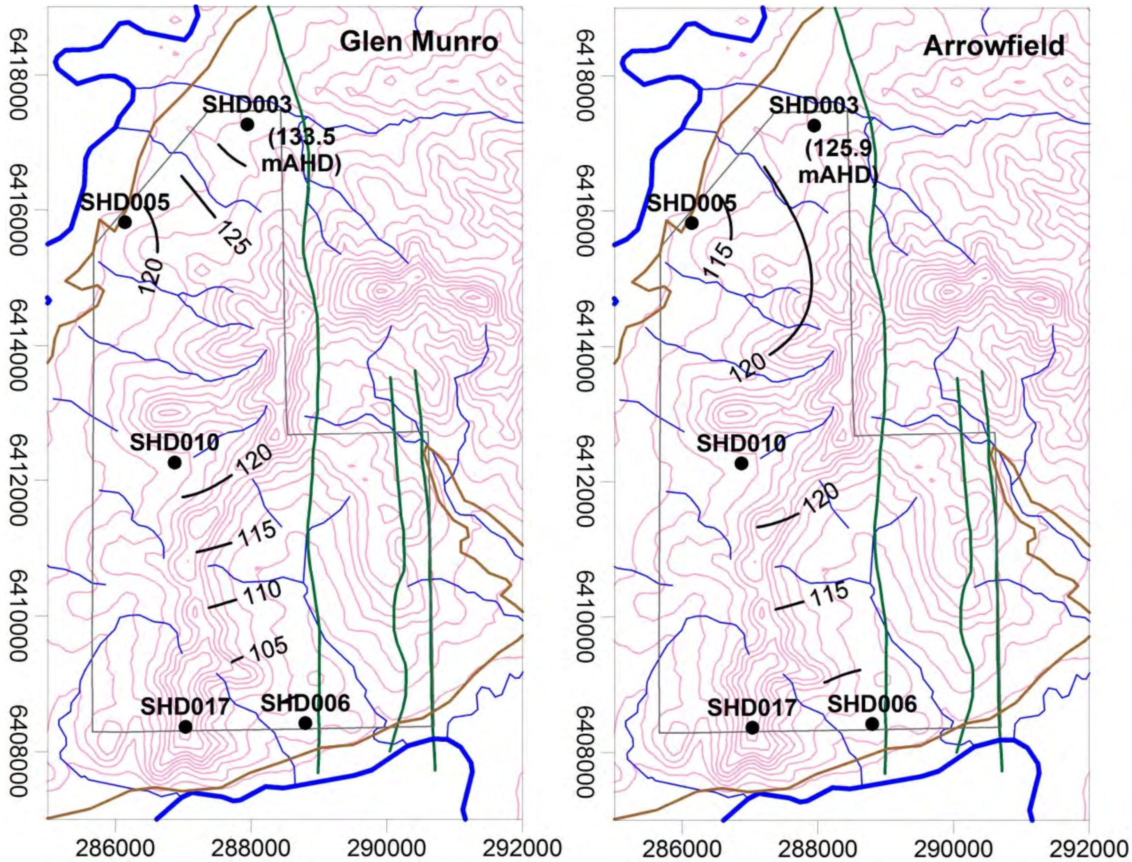


Source: Topographic Base - Department of Lands, 2009; MGBS, 2013 and Geological and Mining Services Australia, 2013

SPUR HILL UNDERGROUND COKING COAL PROJECT

FIGURE 10
Stratigraphy

SPUR HILL UNDERGROUND COKING COAL



Notes: Black dots = vibrating wire piezometers; green lines = geological structures.

Figure 11 Interpolated hydraulic head surfaces in the vertical vicinity of the Glen Munro and Arrowfield Seams for January 2013.

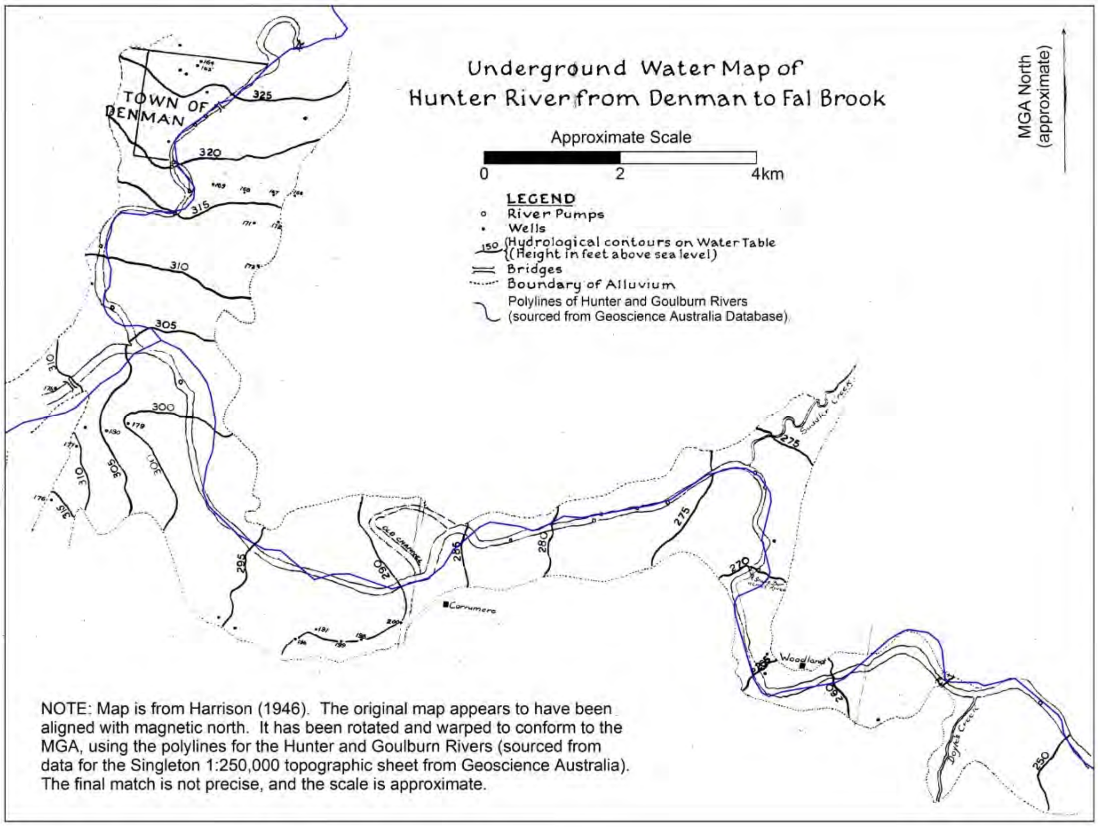


Figure 12 **Interpolated Watertable for the Hunter Alluvium (after Harrison, 1946)**

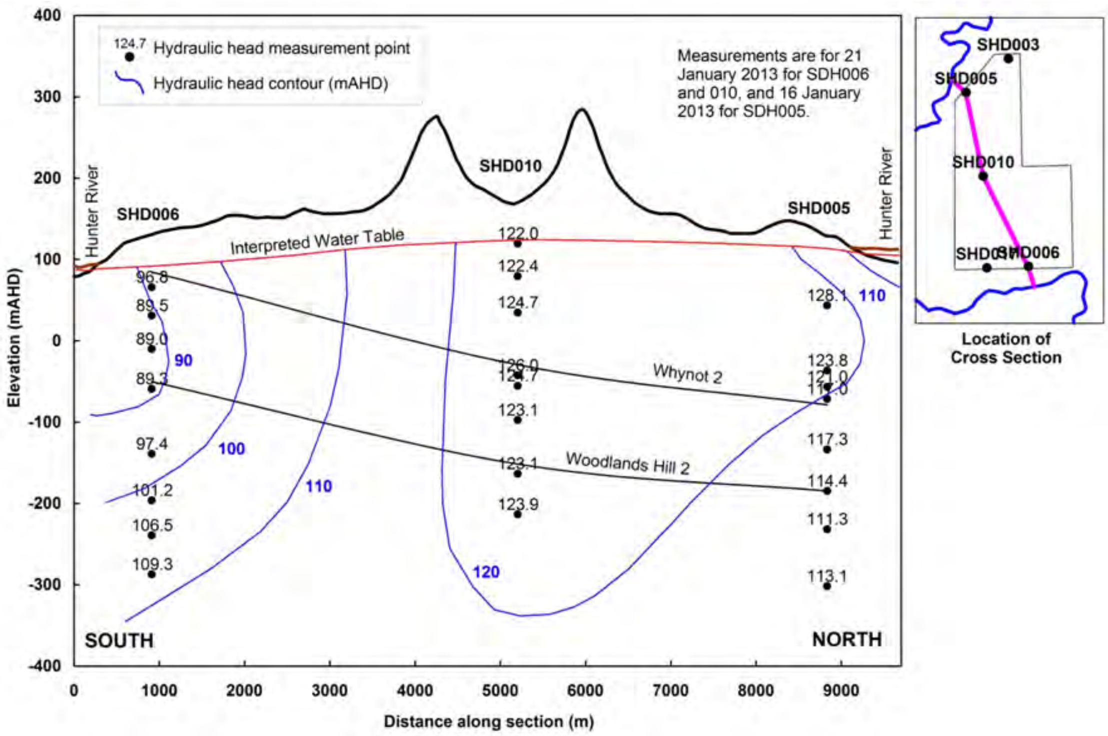


Figure 13 **Hydraulic Head Cross-Section for January 2013.**

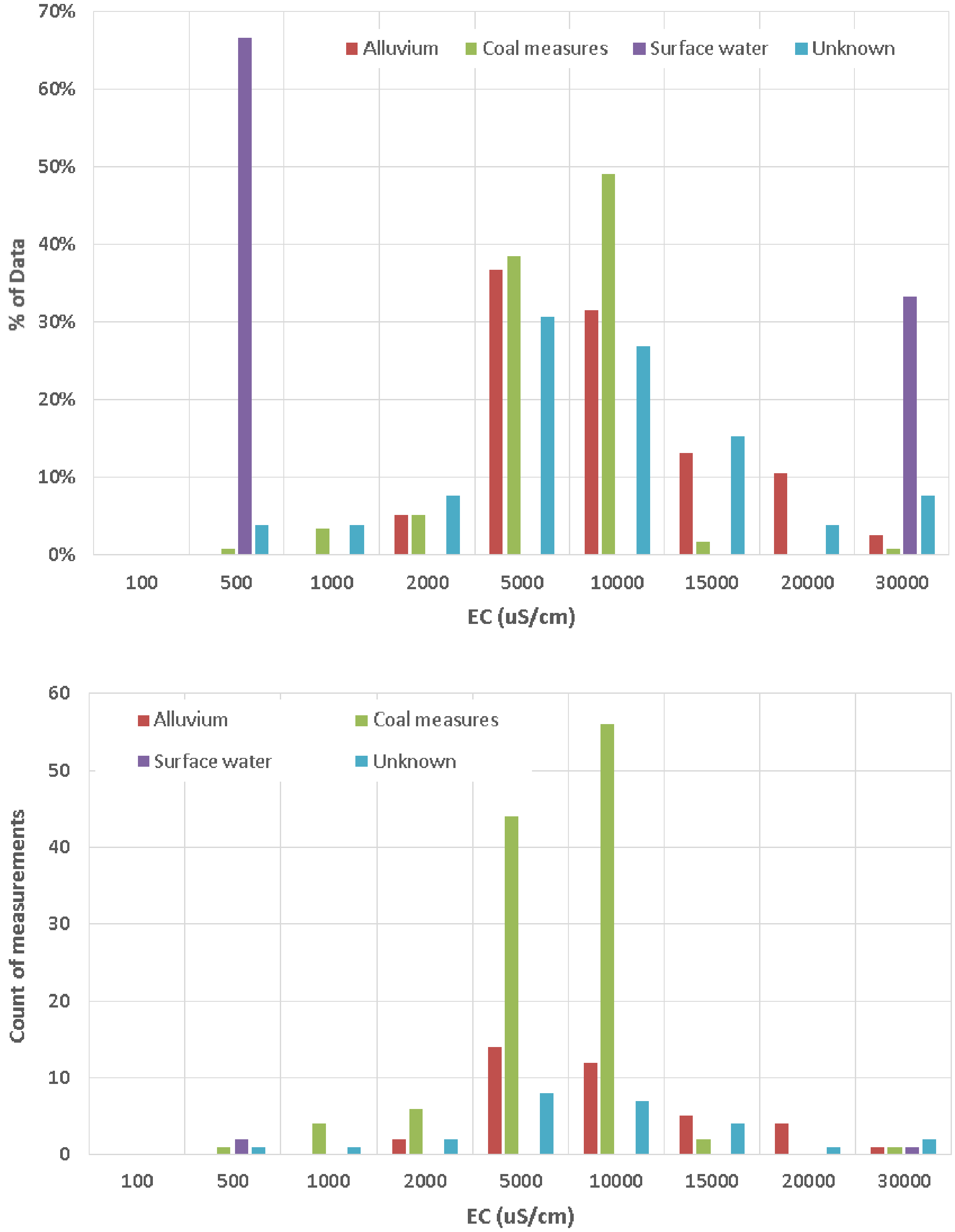
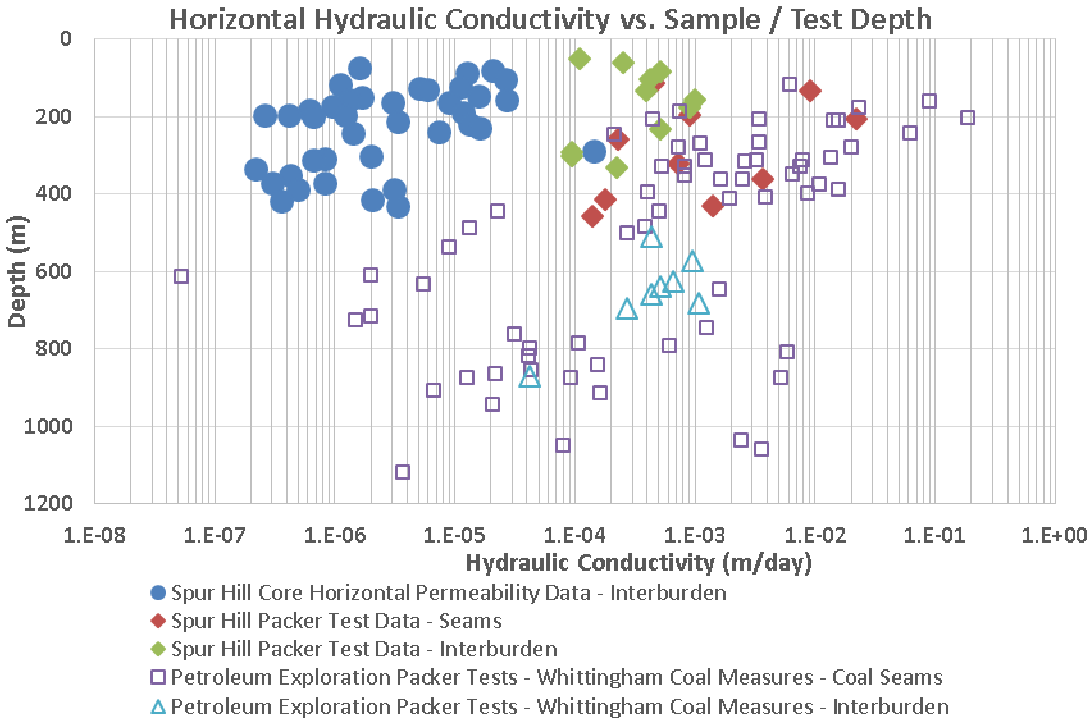


Figure 14 Regional Groundwater EC Data Summary



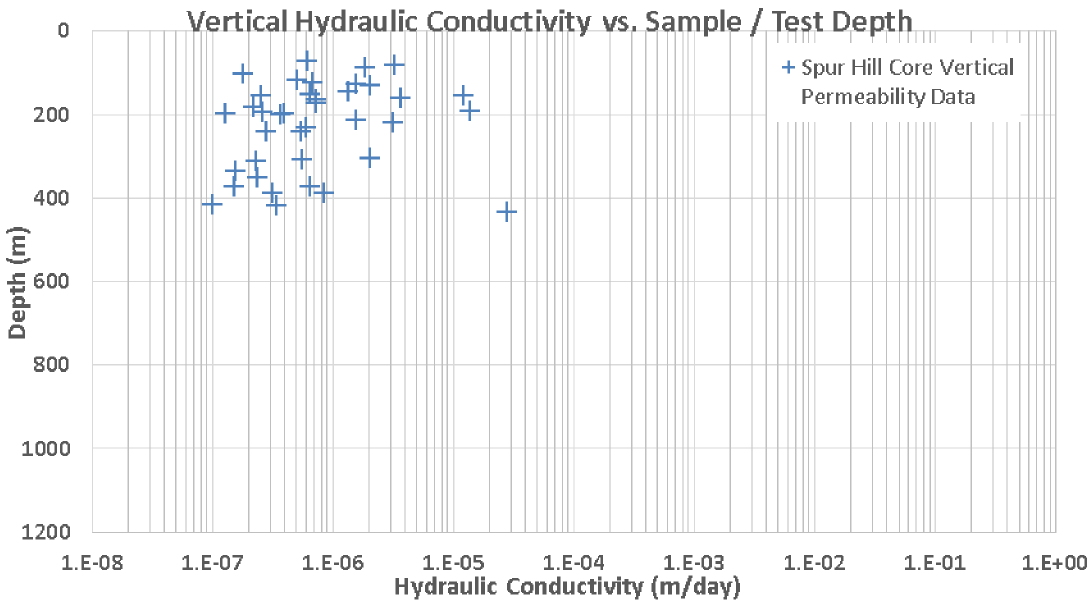
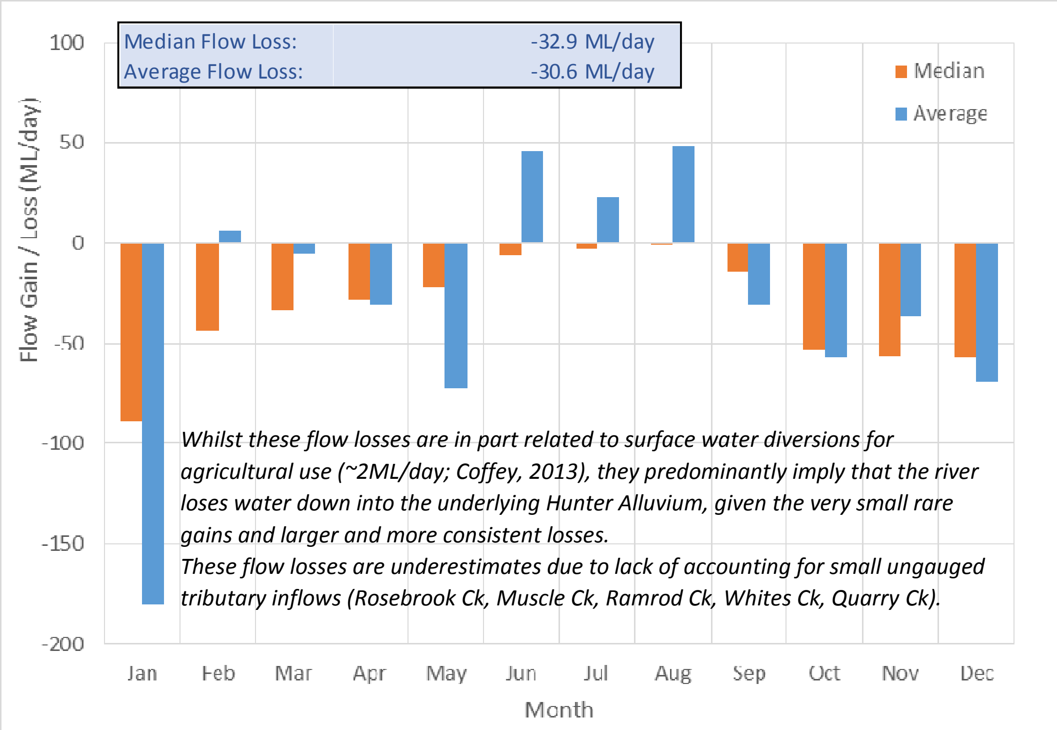
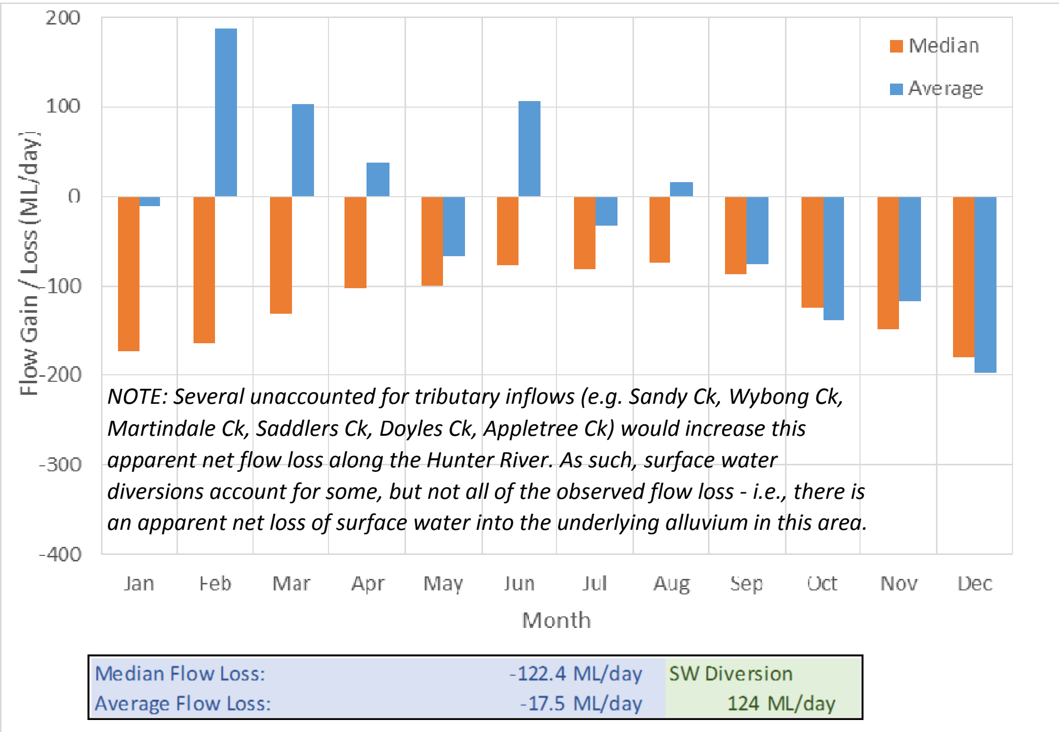


Figure 15 Hydraulic Conductivity Data Summary



NOTE: Analysis conducted on 7-day moving averages to remove travel time effects.

Figure 16 Monthly Flow Gain/Loss on the Hunter River Between Muswellbrook and Denman (1959-2013)



NOTES: Analysis conducted on 7-day moving averages to remove travel time effects. SW= Surface Water.

Figure 17 Monthly Flow Gain/Loss on the Hunter River Between Muswellbrook and Liddell (1913-2013)

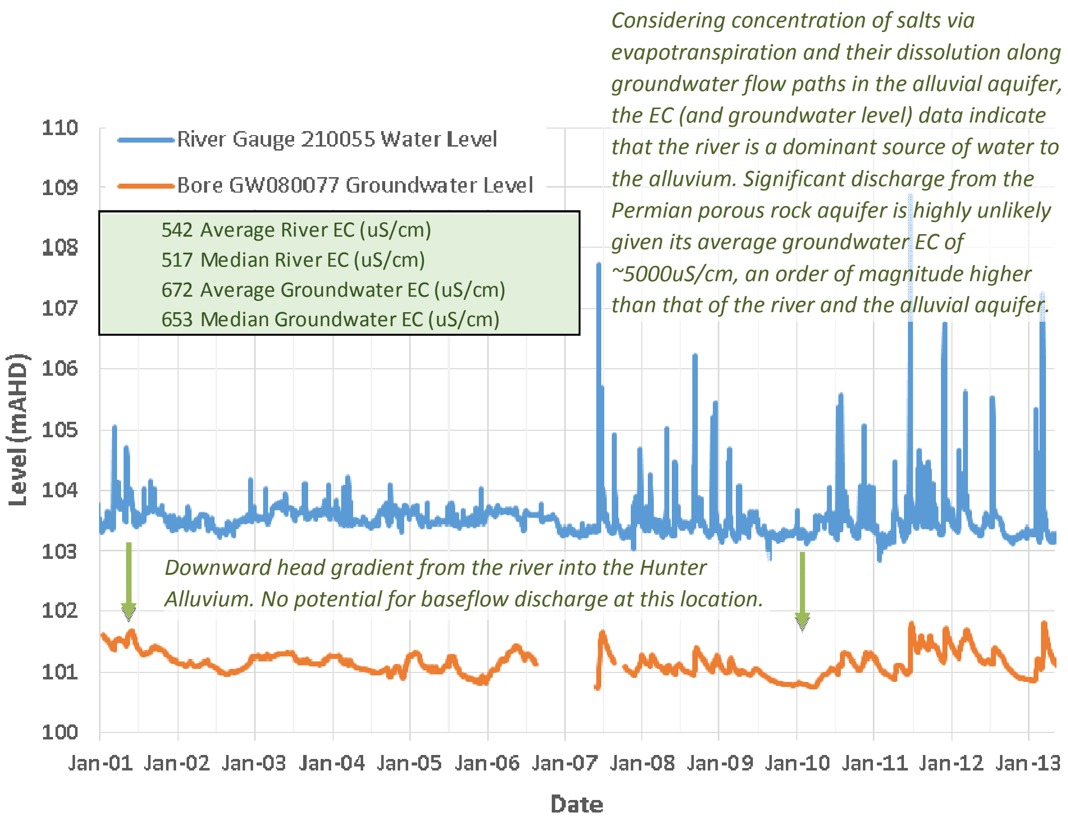
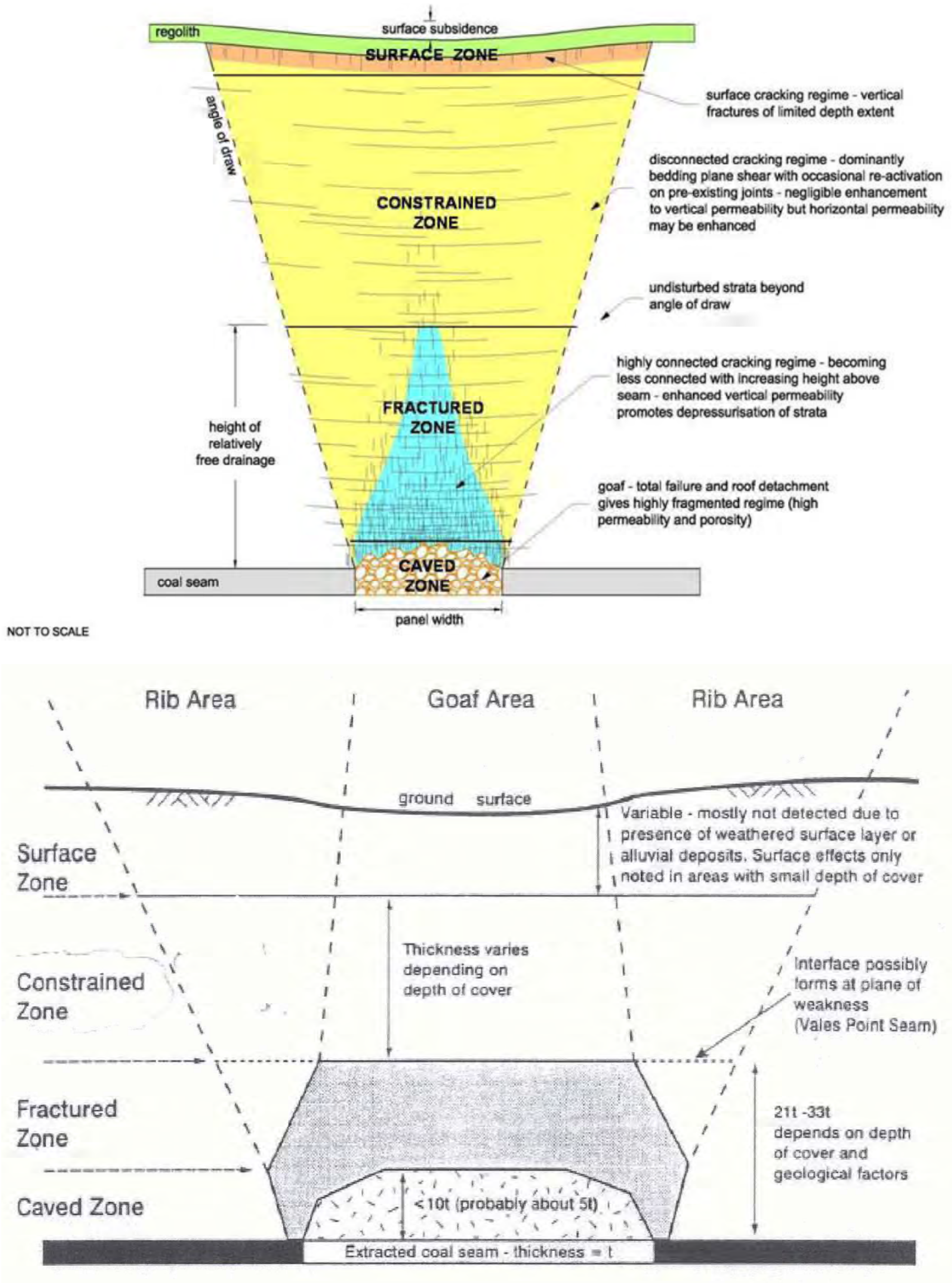


Figure 18 Comparison of Hunter Alluvium Groundwater Level and Hunter River Water Level



Sources: Forster (1995); New South Wales Government Department of Planning (2008).

Figure 19 Conceptual Model of Longwall Mining-Induced Rock Deformation

3 GROUNDWATER SIMULATION MODEL

3.1 MODEL SOFTWARE AND COMPLEXITY

Groundwater modelling has been conducted in accordance with the Murray-Darling Basin Commission (MDBC) Groundwater Flow Modelling Guideline (MDBC, 2001). As this is mostly a generic guide, there are no specific guidelines on special applications such as coal mine modelling. New National Guidelines were announced in June 2012, sponsored by the National Water Commission (Barnett *et al*., 2012). These guidelines build on the 2001 MDBC guide, with substantial consistency in the model conceptualisation, design, construction and calibration principles, and the performance and review criteria, although there are differences in details. In the new guide, there are no specific guidelines on coal mine modelling.

The 2012 guide has replaced the model complexity classification of MDBC (2001) by a "model confidence level". The Project model may be classified as Class 2 (effectively “medium confidence”), which is an appropriate level for this project context. Under the 2001 modelling guideline, the model is best categorised as an Impact Assessment Model of medium complexity. The guide (MDBC, 2001) describes this model type as follows:

“Impact Assessment model - a moderate complexity model, requiring more data and a better understanding of the groundwater system dynamics, and suitable for predicting the impacts of proposed developments or management policies.”

Numerical modelling has been undertaken using the Groundwater Vistas (Version 6 software interface marketed by Environmental Simulations Inc. (ESI) in conjunction with MODFLOW-SURFACT (Version 4) distributed commercially by Hydrogeologic, Inc. (Virginia, USA). MODFLOW-SURFACT is an advanced version of the popular MODFLOW code developed by the United States Geological Survey (Harbaugh and McDonald, 1996). MODFLOW is the most widely used code for groundwater modelling and is accepted as an industry standard.

MODFLOW-SURFACT is a three-dimensional modelling code that is able to simulate variably saturated flow and can handle desaturation and resaturation of multiple aquifers without the “dry cell” problems of standard MODFLOW. This is pertinent to the dewatering of layers within underground coal mines. Standard MODFLOW can handle this to some extent, but model cells that are dewatered (reduced below atmospheric pressure) are replaced by “dry cells”.

The most recent derivation of MODFLOW-SURFACT also allows the changing of model properties through time using the TMP package, allowing mine scheduling to be run within a single model.

The model complexity is adequate for simulating contrasts in hydraulic properties and hydraulic gradients that may be associated with changes to the groundwater system as a result of the proposed development.

3.2 MODEL LAYERS AND GEOMETRY

The model domain is discretised into 90,640 cells comprising 103 rows, 88 columns and 10 layers. Figure 20 shows the extent of the groundwater model domain, which extends 29.9 km from west to east and 35 km from south to north, covering an area of approximately 1048 km^2.

Because this preliminary groundwater assessment is for the Gateway process, which requires a simpler than usual modelling approach, a laterally- and vertically-coarser model grid than might normally be chosen, say for an EIS assessment, has been used. This speeds up the model build and model run components of this assessment, which facilitates the risk (uncertainty) assessment approach. Based on the proposed width of the longwall panels at the Project (340 metres), a uniform grid size of 340 m has been selected.

The 10 model layers used to represent the regional stratigraphic section are outlined in Table 6, and are based on the conceptual hydrogeology described in Section 2.

Table 6 Model Layer Assignment

Layer	Lithology	Median Thickness (m)	Lumped Units
1	Alluvium and Colluvium/Regolith	20	Deep and shallow alluvials
2	Permian (Whybrow) Overburden	108	Denman Formation, Newcastle Coal Measures
3	Whybrow Seam	2.2	
4	Whybrow-Whynot Interburden	86	Redbank Ck and Wambo seams and interburden
5	Whynot Seam	3	
6	Whynot-Bowfield Interburden	202	Blakefield, Saxonvale, Glen Munro, Woodlands Hill seams and interburden; Milbrodale Formation, Arrowfield seam and interburden
7	Bowfield Seam	1.3	
8	Bowfield-Warkworth Interburden	26	
9	Warkworth Seam	2.8	
10*	Permian Underburden	174	Fairford Formation; Mt Arthur, Piercefield, Vaux, Broonie, Bayswater and Ravensworth seams and interburden; Archerfield Sandstone; Bulga Formation; Lemington-Wynn, Pikes Gully-Bengalla, Arties-Edenglassie, Liddell-Ramroad Ck seams and interburden.

* This layer defined based on deepest seam mined at Mt Arthur (Ramrod Ck). It comprises most of the Vane Subgroup, and lower portions of the Jerrys Plains Subgroup.

Geological surface information from surrounding mines was extracted from publicly available reports where possible (AGE, 2012; AGE, 2013; MER, 2006). Within the exploration licence area, geological surfaces were extracted from the SHM geological resource model. The coarse regional scale geological surface mapping in the accompanying notes of the Hunter Coalfield Geological Map (Beckett, 1988) was also used in constructing the modelled geological surfaces; these comprised the floor of the Vane Subgroup, and the floor of the Newcastle Coal Measures.

The subcrop mapping of the 1:100,000 scale Hunter Coalfield Geological Map (NSW Department of Mineral Resources [DMR], 1993) was used to constrain the subsurface extent of each modelled hydrostratigraphic unit.

The 25 m resolution SHM Digital Elevation Model (DEM) was used to define the modelled land surface.

The depth of Hunter Alluvium (layer 1) was estimated using the information presented in Section 2, in conjunction with that from surrounding mines reports, and NOW bore data. The depth of regolith (also layer 1) was estimated using start of coring exploration data from the exploration licence area, in conjunction with information from surrounding mines reports.

The thickness of each modelled coal seam was extrapolated from the exploration licence geological model's median seam thickness data.

Minimum model layer thickness was set to 1 m for all layers, with the exception of layer 1, which was assigned a minimum thickness of 10 m. It should be noted that all layers are fully present across the active model area. Where a layer becomes inactive, such as up-dip from its subcrop, the layer has been extended across the rest of the model domain as a 1 m thick 'dummy' layer, which has the same properties as the first 'active' underlying layer that exists in that area. This approach allows each layer to represent a single hydrogeological unit, so that impacts on specific hydrogeological units can be readily extracted from the model output files.

The resulting modelled geological surfaces are presented in Attachment A.

A representative east-west model cross-section is presented in Figure 21 for northing 6412490 (GDA94 Zone 55) (model row 52) passing through the Project area.

The model domain has been designed to be large enough to prevent significant boundary effects on model outcomes associated with mining-related stress on the groundwater environment as a result of mining at the Project. The model extends beyond the subcrop trace of the deepest coal seam that is likely to be mined by the Project and/or surrounding mines in the future.

3.3 BOUNDARY CONDITIONS

The model domain and boundaries shown in Figure 20 have been selected to incorporate any potential receptors (i.e. surface water bodies) that could be adversely affected by mining. Following is detailed information on each of the modelled boundary conditions.

3.3.1 Watercourses

Creeks and rivers throughout the model domain were modelled using MODFLOW's Stream Flow Routing (SFR1) package (Prudic et al., 2004). This boundary condition routes accumulated stream flows down the stream network from headwaters to catchment outlets. It can also simulate extractions from and discharges to watercourses. It is also capable of simulating stream stage dynamics using Manning's equation, which was employed in this case using a wide rectangular channel assumption (Manning's n was set to a constant value of 6.25E-7 days/m, based on calibration to median water depth data on the Hunter River).

For this Project's steady-state models, gauged median daily stream flows were routed down the Hunter River (from Muswellbrook Bridge gauge 210002; 356 ML/day), and down the Goulburn River (from Sandy Hollow gauge 210031; 104 ML/day). In the transient verification model (Section 3.9), gauged average daily flows were routed down these rivers for each modelled monthly stress period. For all tributaries, only accumulated baseflow was routed down these streams, as defined dynamically based on simulated groundwater levels and stream stages during each model run.

Stream bed hydraulic conductivity was conservatively set to 1 m/day and stream bed thicknesses were set to 0.1 m. Sensitivity analysis of the model calibration and simulated baseflows to stream bed conductivity was conducted, which showed that the model is not significantly sensitive to varying this parameter from 1 m/day down to 0.1 m/day or 0.01 m/day. The Hunter River remained a key source of water to the alluvial aquifer, which is in agreement with the data analysis, independent studies and conceptualisation presented in Section 2.

Stream channel widths were set to 20 m along the Hunter River, 10 m along the Goulburn River, and 2 m in all other streams. These values were based on aerial imagery and field inspection.

Stream bed elevations were parameterised as the minimum value of the 25 m DEM within each 340 m groundwater model grid cell.

3.3.2 Recharge

Recharge to the groundwater system was used as a model calibration parameter over a range of zones based on geological outcrop and subcrop, and topographic slope. For the transient verification model, the calibrated steady-state recharge value was distributed in time (across stress periods) using the sliding 5-year average cumulative departure from mean rainfall trend for Denman presented in Figure 6. This results in a reflection of transient soil moisture deficit and recharge lag effects.

For the alluvium, this process was as follows. The typical maximum modelled recharge rate for the alluvium was estimated as approximately 55 mm/year through bore hydrograph analysis of NOW monitoring bore GW080077. The average recharge (approximately 31 mm/year) was estimated via steady-state model calibration, and agrees well with the estimate of Section 2.7. Minimum annual recharge was set to nil. Transient annual recharge was then linearly interpolated between the specified minimum and maximum modelled values for each year based on the 5-year sliding average cumulative departure from mean rainfall relative to the minimum and maximum sliding average value of the full historical data set. Finally, the interpolated annual recharge rates were distributed across the months of each year according to the total monthly rainfall as a proportion of the total annual rainfall.

Modelled transient recharge for all other recharge zones followed the same approach, but values were scaled according to the calibrated steady-state model's average annual recharge for each zone.

3.3.3 Evapotranspiration

The MODFLOW Evapotranspiration package was used to simulate evapotranspiration from the groundwater system. Extinction depths were set to 2 m below ground. Maximum potential rates were set to 500 mm/year, which is below the BoM's estimated actual evapotranspiration rates for the area (650 mm/year), to account for evapotranspiration from the unsaturated zone, which is neglected in this model configuration. For the transient verification model this value was distributed across months according to the average monthly potential evaporation profile presented in Table 4.

3.3.4 Surrounding Hydrostratigraphic Units

Areas of the edge of the model domain where modelled HSUs were active (primarily in the west, north and south) were assigned as MODFLOW General Head Boundaries (GHBs). This allows for groundwater flow down-basin. GHBs simulate groundwater flow into and/or out of the model domain according to a specified head and conductance.

Specified GHB heads were iteratively assigned based on the calibrated model's steady-state heads. GHB conductances were assigned based on cell dimensions (thicknesses and widths), calibrated hydraulic conductivities of each model layer, and the assumption of a 1 m length dimension. As such, conductance values averaged 1.6 square metres per day (m^2/day), and ranged from 0.006 to 377 m^2/day within two standard deviations of the mean (calculated on a log base 10 scale).

3.3.5 Groundwater Use

Existing registered NOW groundwater bores and those of the Project bore census (Section 2.6.1; GES, 2013) were included in the model using the Fracture Well (FWL4) package. These are shown in Figure 7 and Figure 20. Rates were assumed to be 50% of licensed rates as obtained directly from NOW, and 1 ML/year for stock and domestic bores.

3.3.6 No Flow Boundaries

The northeastern corner of the model was inactivated where the 10 modelled HSUs pinch out, and older units are at outcrop.

3.3.7 Mine Workings

The proposed Project underground mining and dewatering activity was defined in the predictive models using MODFLOW Drain cells within the mined coal seams. Modelled drain elevations were set to 0.1 m above the base of each worked seam. These drain cells were applied wherever workings occur, and were progressed through annual or coarser temporal increments in the transient model setup (see Section 4.1 for further details). A drain conductance value of 1000 m^2/day was applied.

Hydraulic parameters were also changed with time in the goaf and overlying fractured zones directly after mining of each longwall panel (see Section 3.5 for details), whilst simultaneously activating drain cells along advancing development headings. The development headings were activated one stress period in advance of the active mining and subsequent subsidence. Although the coal seam void should be dominated by the drain mechanism, the horizontal and vertical permeabilities were raised to 10 m/day to simulate the highly disturbed nature of materials within the caved zone (see Section 2.7).

Although surrounding mines were not modelled for this preliminary groundwater assessment for the Gateway process, the principle of superposition was used to conservatively estimate cumulative impacts of all mines, including the Project (see Section 3.7.3).

3.4 HYDRAULIC PROPERTIES

The modelled hydraulic zones and values are reflective of the conceptual (and geological) model. The distributions of hydraulic properties in each model layer are shown in Attachment B.

The coal measures were coarsely split into multiple layers in recognition of the vertical hydraulic gradient through the stratigraphic column and the need to represent the various target coal seams as separate model layers, but to a level of detail in keeping with this simple preliminary groundwater assessment for the Gateway process (see Table 6).

Previous studies and investigations within the region, in conjunction with core and packer testing data collected for the Project, provided the initial basis for chosen hydraulic property parameters used within the modelling component of this Project for the coal seams and interburden.

The hydraulic properties in Table 7 are indicative hydraulic conductivities for the various stratigraphic units incorporated into the groundwater model. These were based on a combination of the measured data and the calibration parameterisations of surrounding mines' models. Although automated sensitivity was used in the steady-state calibration process, care was taken to ensure that the hydraulic properties reflect the measured and estimated ranges for each of the strata types, as discussed in Section 2.6.3. These values were subsequently checked during transient verification.

Table 7 Indicative Hydraulic Properties of Stratigraphic Units

Layer		Zone	Kx (m/day)	Kz (m/day)
1	Alluvium	101	8.0	0.03
1	Colluvium / Regolith	102	0.1	1.0E-02
2	Permian (Whybrow) Overburden (Denman Formation / Newcastle Coal Measures)	2	1.0E-04	5.0E-06
3	Whybrow Seam	3	2.5E-03	1.5E-05
4	Whybrow Seam – Whynot Seam Interburden	4	1.0E-4	2.0E-06
5	Whynot Seam	5	1.2E-3	1.3E-05
6	Whynot Seam – Bowfield Seam Interburden	6	1.0E-4	5.0E-06
7	Bowfield Seam	7	1.5E-3	1.5E-05
8	Bowfield Seam – Warkworth Seam Interburden	8	1.0E-4	2.5E-06
9	Warkworth Seam	9	2.5E-3	1.5E-05
10	Permian Underburden (including Vane subgroup)	10	1.0E-4	7.0E-07

3.5 DEFORMATION OF OVERLYING STRATA

Section 2.7 provides background and conceptual information on the impact of mining on the properties of overlying strata.

3.5.1 Model Simulation

The layer definition within the model has allowed each mined coal seam to be represented individually. A single layer of interburden separates each target coal seam in the model. Because the target coal seams begin in model layer 5, there is flexibility in the model to simulate the fractured zone to various heights. This ensures that the impact of progressive caving and fracturing associated with the mining is adequately represented.

The Project longwall panels are 305 m void width (340 m including pillars), and hence the height of connective cracking was assumed to be about 180 m (60% of void width) but could range from about 120 m (40% of void width) to about 240 m (80% of void width). As the median depth of cover for the shallowest mined (Whynot) seam across the proposed mining area is 213 m, fracturing is unlikely to reach ground surface over significant areas: 0% of the mined area assuming a fracture height of 120 m, up to 5% assuming a height of 180 m, and up to 69% assuming a height of 240 m. Increases in vertical and horizontal permeability have been applied in the Project's numerical modelling up to and including Layer 2 (Denman Formation and Newcastle Coal Measures). A zone of increased horizontal permeability has been applied in the regolith (Layer 1) over the mined areas.

The deformation of overlying strata was simulated with horizontal hydraulic conductivity enhanced by a factor of two (or to 10 m/day within the caved and mined zones). Vertical hydraulic conductivity was enhanced according to a log-linear monotonic (ramp) function. The function varied the vertical hydraulic conductivity field within the deformation zone overlying coal extraction areas and weighted the permeability changes on layer thickness. Limits for the variability were governed by predicted fracture height and assigned upper and lower bounds on hydraulic conductivity in the fractured zone. Assigned fractured zone properties are presented in Table 8. Note that these were calculated from calibrated model host parameter values.

The permeability of the model layer directly beneath underground mined areas was also increased with a uniform increase in vertical hydraulic conductivity of 3 x host values being applied.

Table 8 Calibrated Host Hydraulic Properties and Modelled Hydraulic Properties within the Mined Areas

Layer		Zone	Host Kx (m/day)	Max Deformed Kx (m/day)	Host Kz (m/day)	Max Deformed Kz (m/day)	Host Sy	Deformed Sy
1	Alluvium	101	4.3	N/A	2.5E-02	N/A	0.15	N/A
1	Regolith	102	1	2.0E+00	6.2E-04	N/A	0.1	N/A
2	Permian overburden (Denman Fm/Newcastle Coal Measures)	2	1.0E-04	2.0E-04	4.7E-06	1.4E-05	0.01	N/A
3	Whybrow Seam	3	2.3E-04	4.7E-04	8.3E-06	8.7E-05	0.05	N/A
4	Whybrow Seam – Whynot Seam interburden	4	7.7E-04	1.5E-03	1.5E-04	2.0E-04	0.01	0.03
5	Whynot Seam	5	1.0E-04	1.0E+01	1.7E-06	1.0E+01	0.05	0.1
6	Whynot Seam – Bowfield Seam interburden	6	1.0E-05	2.0E-05	3.3E-06	9.8E-06	0.01	0.01
7	Bowfield Seam	7	1.4E-03	1.0E+01	4.3E-04	1.0E+01	0.05	0.1
8	Bowfield Seam – Warkworth Seam interburden	8	1.0E-05	1.0E+01	2.3E-06	1.0E+01	0.01	0.06
9	Warkworth Seam	9	3.4E-02	1.0E+01	9.9E-05	1.0E+01	0.05	0.1
10	Permian underburden (including Vane subgroup)	10	7.5E-05	8.8E-05	1.3E-06	4.0E-06	0.005	N/A

Similarly, horizontal hydraulic conductivities of the underlying layer were increased by a factor of 2 x the host values. The assumption was made that this only affects the upper 30 m of underlying rock, and as such the conductivity increase was thickness-weighted accordingly.

Storage properties (Sy) were also increased in the coal seam layer to 10% for the longwalls. For the layers above each mined coal seam Sy was increased according to the extension of the rock mass and increase in porosity due to caving-induced subsidence above each longwall panel. Caving was assumed to occur over a height equal to 10 x the mined seam thickness, and the resulting increase in porosity (and Sy) was assigned to the overlying layer by thickness-weighting the deformed and host porosities of the caved and host zones, respectively. The assigned fractured zone properties are presented in Table 8. Note that these were calculated from calibrated model host parameter values.

For the deformation of strata during the prediction period, the properties were changed using HSU zonation and the TMP package of SURFACT 4 which allows varying property values with time. Fracturing was instigated by altering host properties in accordance with mine progression using a ratio multiplier within the HSU zoning feature.

Further investigations into the impact of mining on the properties of overlying strata on hydraulic properties would be conducted as part of the EIS process.

3.6 MODEL VARIANTS

Both steady-state and transient models were developed for use in this groundwater assessment as summarised below:

- Steady-state model of pre-mining conditions: Calibration against the observed pre-mining groundwater levels. This model was used to formulate transient model starting heads;
- An additional 179 calibrated steady-state models, as discussed in Section 3.8, for predictive modelling and uncertainty analysis in this preliminary groundwater assessment for the Gateway process;
- Transient verification model (pre-mining; January 2001 – April 2013). Verification against the groundwater hydrographs in Attachment C; and
- 180 transient predictive models extending to the end of mining (22 years), and 1000 years post-mining recovery.

3.7 STEADY-STATE CALIBRATION

3.7.1 Approach

Steady-state (or baseline 'long term') calibration was carried out as the primary model calibration process for this preliminary groundwater assessment. The steady-state model was calibrated to groundwater levels from a variety of sources including the vibrating wire piezometers installed for the Project in 2012 (Section 2.6), bore census data collected specifically for the Project, pre-mining calibration data from publicly available reports for nearby mines (Drayton South and Mt Arthur; AGE, 2012; AGE, 2013), NOW monitoring bores (active and inactive), and NOW time of drilling water level records. In the case of the vibrating wire piezometers on EL7429, the latest record was selected for steady-state calibration, because several of these piezometers appear to still be equilibrating.

The calibration data set comprised 103 head targets and 111 vertical head difference targets. The model was calibrated using a combination of auto-sensitivity analysis (PEST; Doherty, 2010) and manual modification of zones and model parameters. Greater weight was placed on what were considered reliable vibrating wire piezometer data from EL7429, the Project bore census data, and on the NOW monitoring bore data. Comparatively low weights were placed on the time of drilling water levels.

3.7.2 Results

Steady-state head calibration performance is good (Figure 22a) at 5.5% Scaled Root Mean Square (SRMS; Table 9), which is below the target 10% SRMS suggested in the MDBC flow model guideline (MDBC, 2001). The 2012 Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012) warn against prescriptive performance targets but note that "*Targets such as SRMS < 5% or SRMS < 10% ... may provide useful guides*". The vast majority of calibrated model heads were within 10 m of observed values, and 40% were within 5 m (Figure 22b). There is no significant bias in the modelled groundwater levels.

Table 9 Steady-State Head Calibration Statistics

Performance Statistic	Value
Number of Observation Bores	103
Number of Data Points	103
Root Mean Square (m)	8.2
Scaled Root Mean Square (SRMS) (%)	5.5

Figure 23 presents the calibrated model water table, and a map of the head calibration error ("Bore GWL Residual") throughout the model domain. In general, the head calibration is better within the alluvials, the EL7429 area, and in the vicinity of the Drayton South mine to the east. Head errors increase within the Mt Arthur mining lease to the northeast, and to the south of this area along the eastern model boundary. This issue could be due to historical and ongoing mining impacts on the observed water level data in these areas.

Although vertical head differences were used as supplementary targets, the model was not able to reproduce the values accurately, due probably to the following factors:

- The accuracy of the vertical position of the vibrating wire piezometers;
- The ongoing equilibration of the piezometers; and
- The lumping of multiple seam and interburden units within single model layers, particularly layers 4 and 6 (see Table 6). The vibrating wire piezometers target a number of these lumped seams and interburden units, and hence the model cannot be expected to simulate the observed vertical head differences. This could be improved in subsequent EIS modelling with more detailed model layer stratification.

3.7.3 Steady-State Model Water Balance

Modelled mass balance error was good at less than 1%, which is within the typically acceptable range.

There are multiple opportunities for groundwater to discharge from and recharge to the groundwater system. Those implemented in the model include:

- Baseflow to and leakage from streams (represented by the Stream Flow Routing cells in MODFLOW);
- Outflow / inflow to / from down-basin (represented by General Heads in MODFLOW);
- Evapotranspiration from shallow groundwater (represented by Evapotranspiration cells in MODFLOW); and
- Groundwater use (represented by Fracture Wells in MODFLOW).

In addition to the water balance components described above, existing nearby mine workings also extract groundwater from the system. These were not simulated in this preliminary groundwater assessment for the Gateway process, because the principle of superposition was used to assess the cumulative impacts of all mines. Whilst superposition is not strictly valid in non-linear systems such as unconfined aquifers, it provides a simple means of assessing cumulative impacts of neighbouring mines, which is in keeping with the simple modelling required of the Gateway process.

The water balance for the steady-state calibration model across the entire model area is summarised in Table 10. The total inflow (recharge) to the aquifer system is approximately 55 ML/day, comprising rainfall recharge (35%), and leakage from streams into the aquifer (65%). Boundary inflow is negligible.

Groundwater discharge is dominated by evapotranspiration (72%), with much of the remainder discharge via bores (25%) and insignificant baseflow discharge to streams (3%). This finding supports conceptualisation of streams being primarily losing systems (see Sections 2.6.4 and 2.7).

Table 10 Calibrated Steady-State Water Balance

Component	Inflow (ML/day)	Outflow (ML/day)
Recharge (Direct Rainfall)	19.0	-
ET (Evapotranspiration)	-	39.7
Wells	-	13.8
Streams (Leakage/Baseflow)	35.8	1.8
Head Dependent Boundary (GHB)	0.04	0.1
Total	54.8	55.3

3.8 ALTERNATIVE STEADY-STATE MODEL REALISATIONS

For the purposes of uncertainty analysis of predictive model results, 200 additional calibrated steady-state models were developed. PEST's RANDPAR utility (Doherty, 2010) was used to generate 200 random parameter sets for the model. The random parameter sets were generated within one order of magnitude either side of the optimal calibrated parameter values discussed in Section 3.7 and 3.10. Each of these 200 random model realisations was then recalibrated using two iterations of the PEST optimisation code.

Of the 200 random model realisations, 179 were considered sufficiently calibrated to be used in the predictive model uncertainty analysis. Each of these 179 realisations possessed SRMS head calibration statistics of less than 10% - not as 'good' as the optimal calibration, but still reasonably well calibrated models.

Hence, a total of 180 calibrated models have been developed for predictive modelling and uncertainty analysis in this preliminary groundwater assessment for the Gateway process.

3.9 TRANSIENT VERIFICATION

Transient verification against observed groundwater levels was carried out for the monitoring bores marked on Figure 7 for the period January 2001 to April 2013, primarily to check that assigned storage parameters were reasonable. Comparison of modelled and observed hydrographs is presented in Attachment C. The assigned aquifer storage properties were considered sufficiently well verified against the observed data.

The simulated seasonal fluctuations in groundwater levels in the NOW alluvial monitoring bores is generally well calibrated, although the observed fluctuations in bore GW080077 in the Hunter alluvium should be larger. This latter point could be due to the use of a single aquifer property zone for the alluvials, in the context of actual localised aquifer property variability. Alternatively, recharge variability may not be adequately simulated. The sensitivity of this simulated bore hydrograph fluctuation to simulated stream stage dynamics was tested and found to be insensitive, which suggests that the cause is local aquifer property, groundwater use, and/or recharge variability. This could be investigated and improved in subsequent EIS modelling.

Simulated vibrating wire piezometer pressures within the lease area are flat, whereas some of the observed data exhibit fluctuations. These are considered non-natural however, and are likely the result of piezometer equilibration given their recent installation (in late 2012).

3.10 CALIBRATED MODEL PARAMETERS

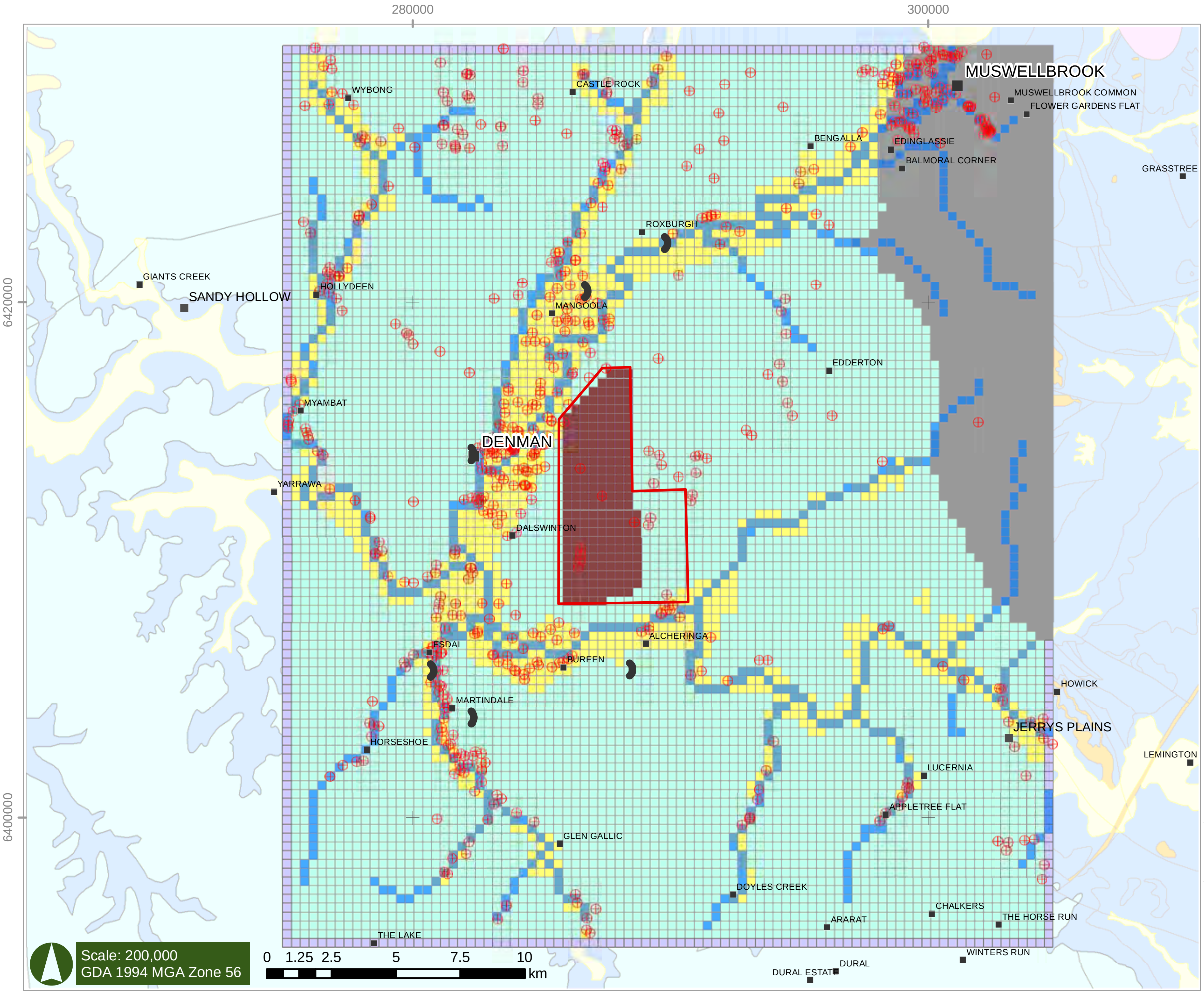
Calibrated model parameters are presented in Table 8 and Figure 24. In terms of horizontal hydraulic conductivities, most are comparable to the starting values presented in Table 7, although they have generally fallen during calibration. Notable exceptions to this trend are the regolith, Whynot overburden and the Warkworth Seam, which have risen during calibration. A similar pattern is seen for vertical hydraulic conductivities, most of which have fallen during calibration, the notable exceptions to this being increased calibrated conductivity of the Whynot overburden and Seam, and the Bowfield and Warkworth Seams.

The general trend towards lower conductivities is in agreement with the core permeability data (Figure 15), and suggests that the rock matrix permeabilities form the dominant regional flow controls, rather than fracture permeabilities.

Calibrated recharge rates are approximately 30 mm/year (around 5% of rainfall) to the alluvium, and generally around 2-3 mm/year (<1% of rainfall) to the Permian outcrop. These values are in agreement with the observed fluctuations in groundwater levels in the alluvium, and the lack of seasonal trends observed in the short available record for the Permian units (see Section 2.7). They are also in agreement with the observed higher salinity of groundwater in the Permian units versus the lower salinity of the alluvium (see Section 2.6.2).

3.10.1 Calibration Sensitivity Analysis

Figure 25 presents the sensitivity of all model parameters used to calibrate the models, as determined by PEST (Doherty, 2010). It is clear that the sensitivity of the calibration to regolith hydraulic conductivity is greatest, followed by the horizontal and vertical hydraulic conductivities of the interburden and underburden units, in addition to recharge. The model is relatively insensitive to the majority of the hydraulic properties of the seams, the exception being the Warkworth Seam (the third most sensitive parameter). Conversely, the model is relatively insensitive to the Warkworth overburden properties.



Legend

- Exploration Lease 7429
- Bore / well (FWL)
- Mine (Drain)
- Stream (SFR)
- General Heads (GHB)
- Watercourse
- inactive cell
- Model grid (340m)

Model geology outcrop

- Alluvium
- Regolith (Permo-Triassic)

Geology outcrop (250k)

- other
- Quaternary
- Tertiary
- Jurassic
- Triassic
- Permian
- Carboniferous

Spur Hill Management
Spur Hill Underground Coal

Figure 20

Groundwater Model Boundary Conditions

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DrawingNo: SHC002-001
Rev: B.
Created by: WMinchin
Date: 16/11/2013.

HYDRO SIMULATIONS

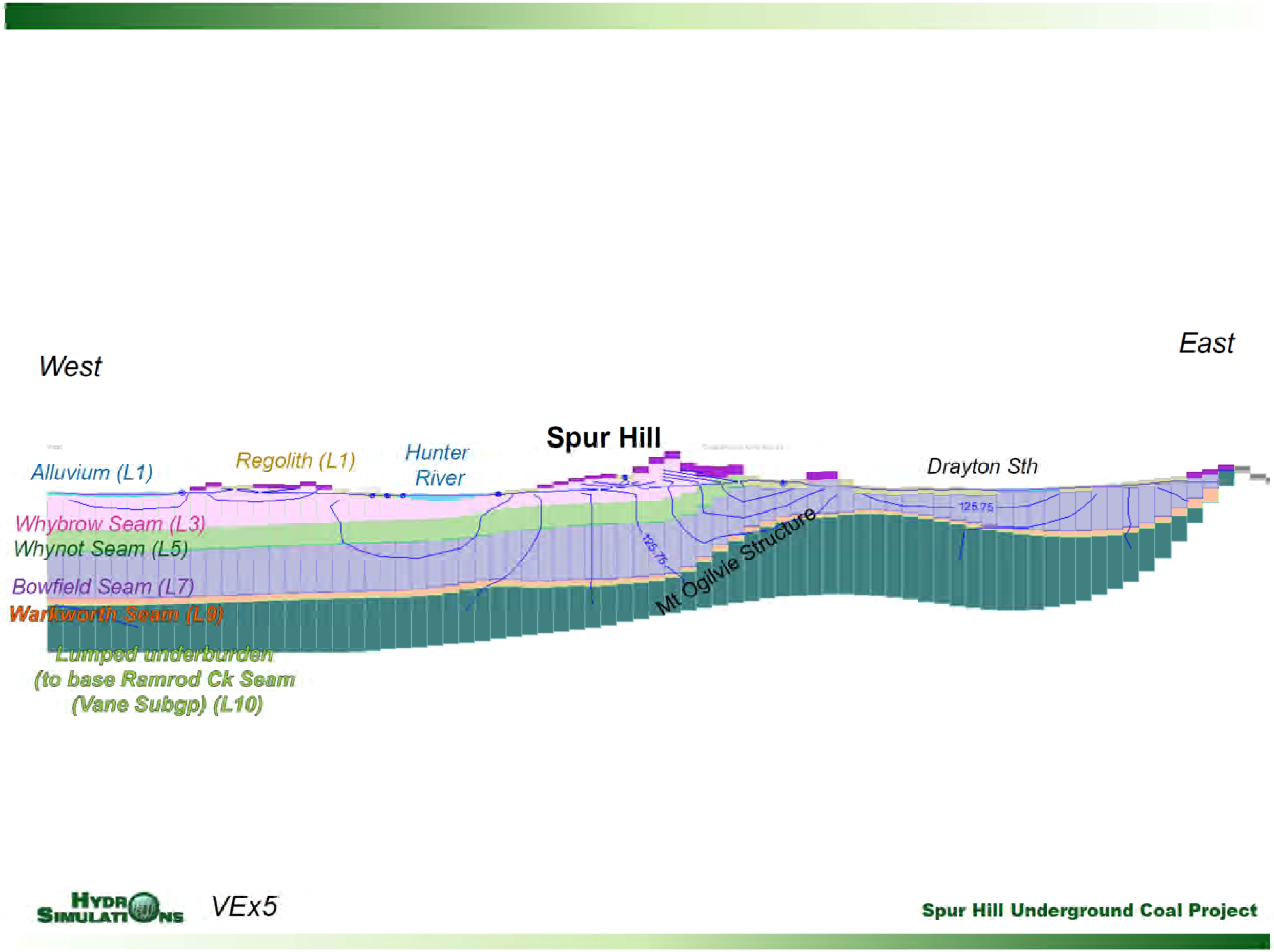
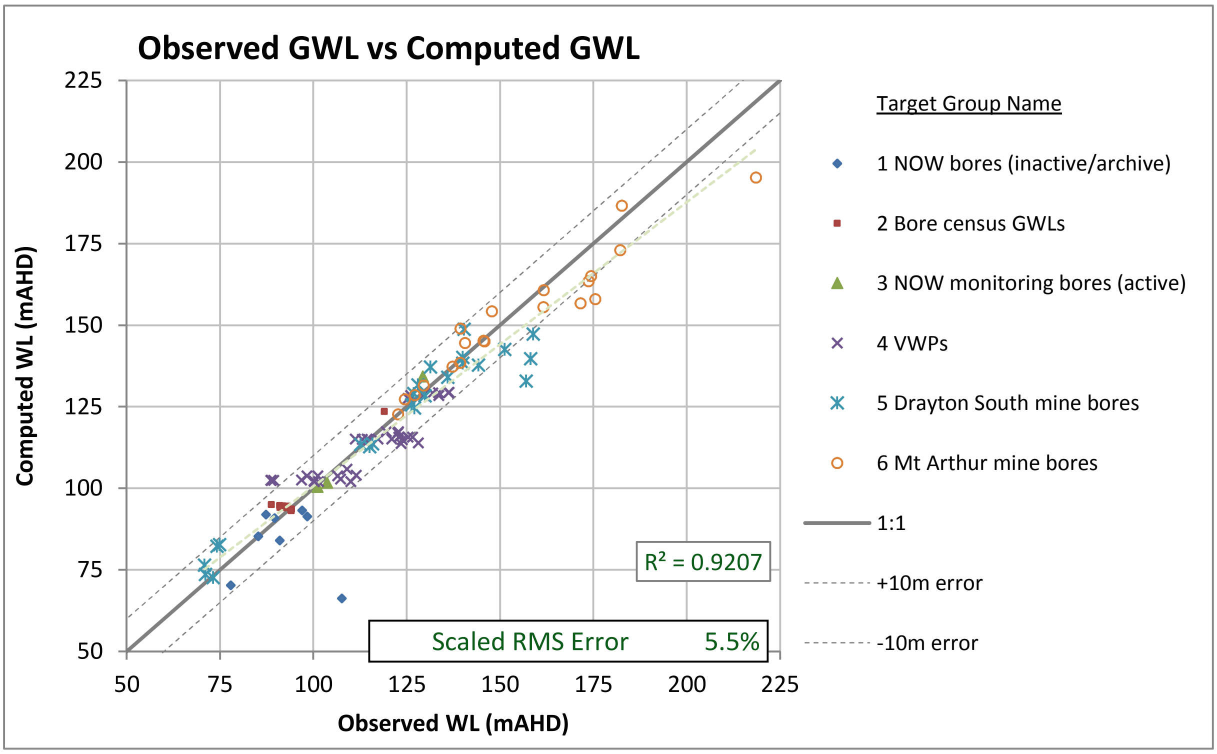
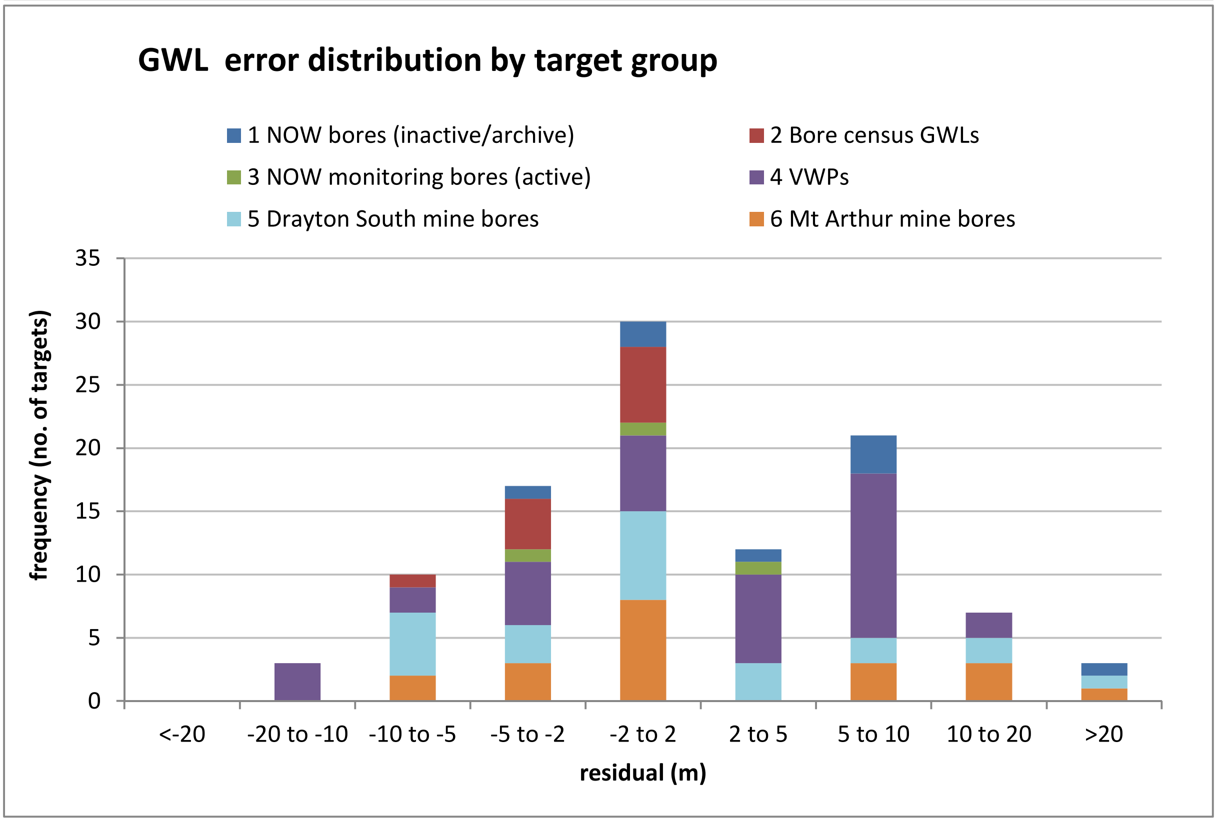


Figure 21 **Representative Model Cross-Section**



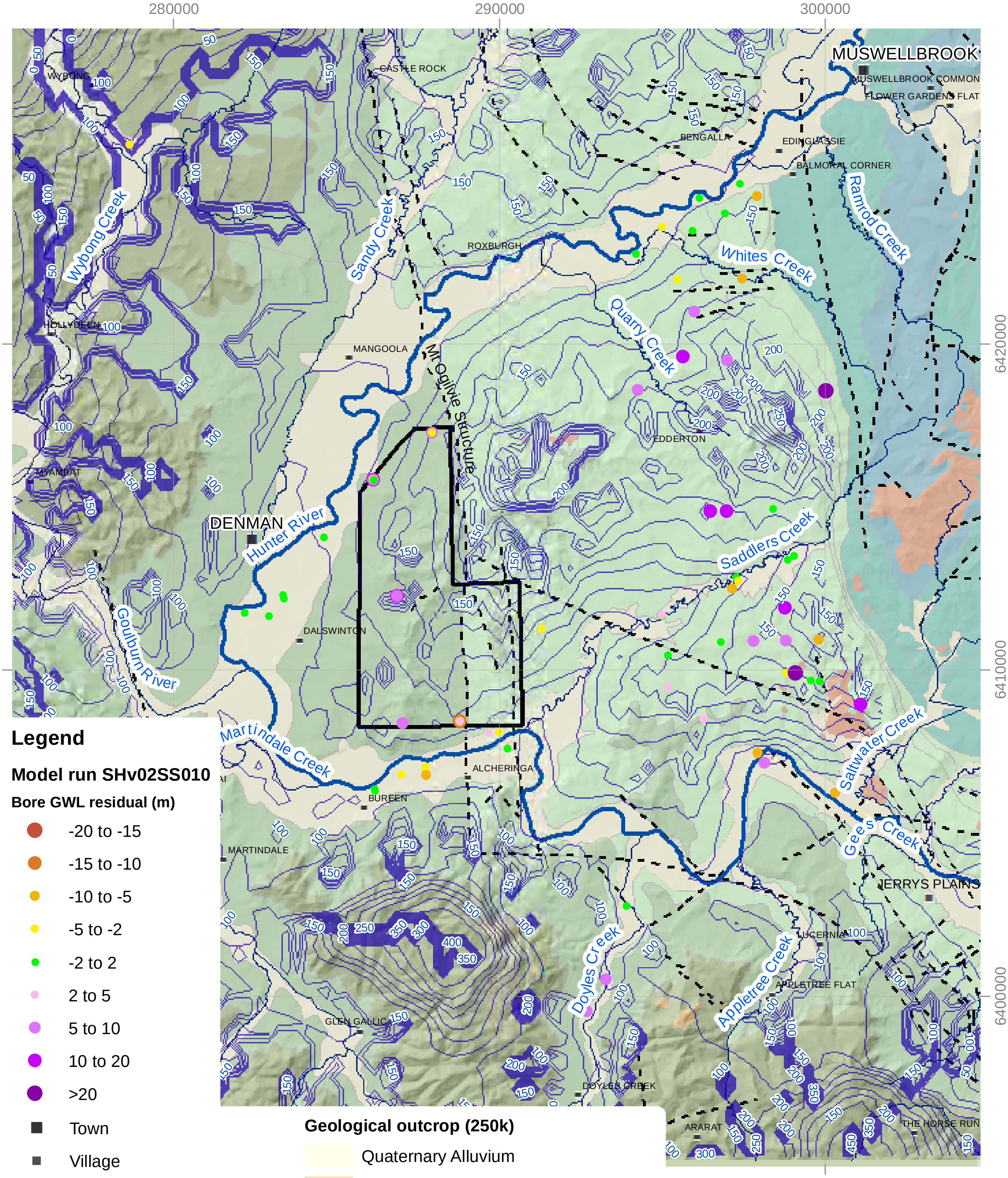


D:\HydroSim\SHC002\GWModel\SHv02SS\Processing\[SHv02SS010_calibration.xlsx]Figure 22

Results from model run: SHv02SS010

HYDRO SIMULATIONS

Summary of model calibration **Figure 22**



Legend

Model run SHv02SS010

Bore GWL residual (m)

- -20 to -15
- -15 to -10
- -10 to -5
- -5 to -2
- -2 to 2
- 2 to 5
- 5 to 10
- 10 to 20
- >20
- Town
- Village
- Locality
- Watercourse
- Simulated water table contour
- Exploration Lease 7429
- Geological Structures

Geological outcrop (250k)

- Quaternary Alluvium
- Tertiary Basalts
- Narrabeen Group (Triassic)
- Jurassic Basalts
- Newcastle Coal Measures (Permian)
- Wittingham Coal Measures (Permian)
- Maitland Group (Permian)
- Greta Coal Measures (Permian)
- Undifferentiated Palaeozoic / Mesozoic

Spur Hill Management
Spur Hill Underground Coal

Figure 23

Steady State Model Calibration

DrawingNo: SHC002-019
Rev: D.
Created by: CNicol
Date: 16/11/2013.

Scale: 165,000
GDA 1994 MGA Zone 56

0 1 2 4 6 8 km

HYDROSIMULATIONS

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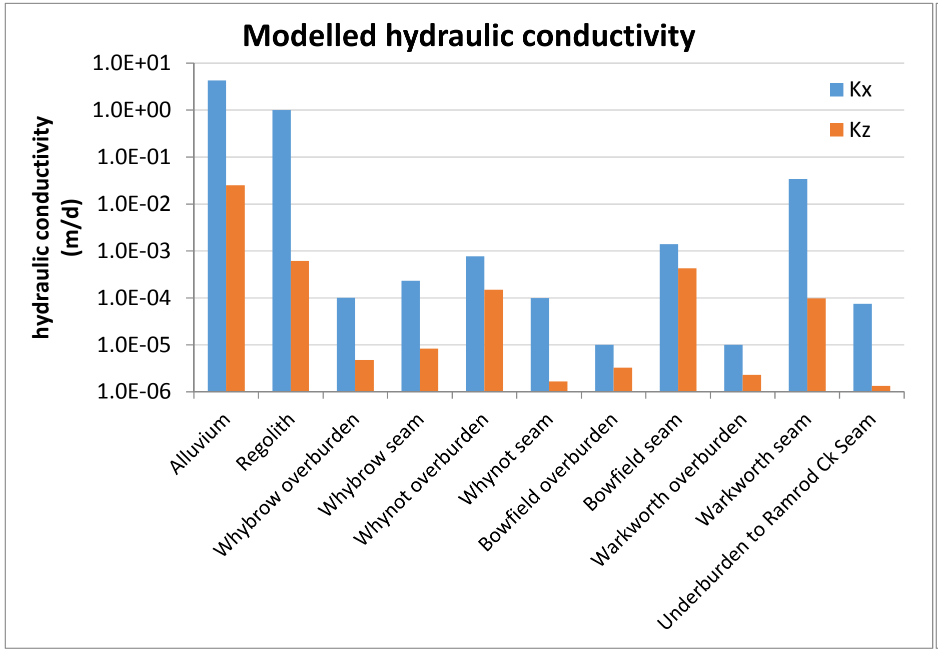
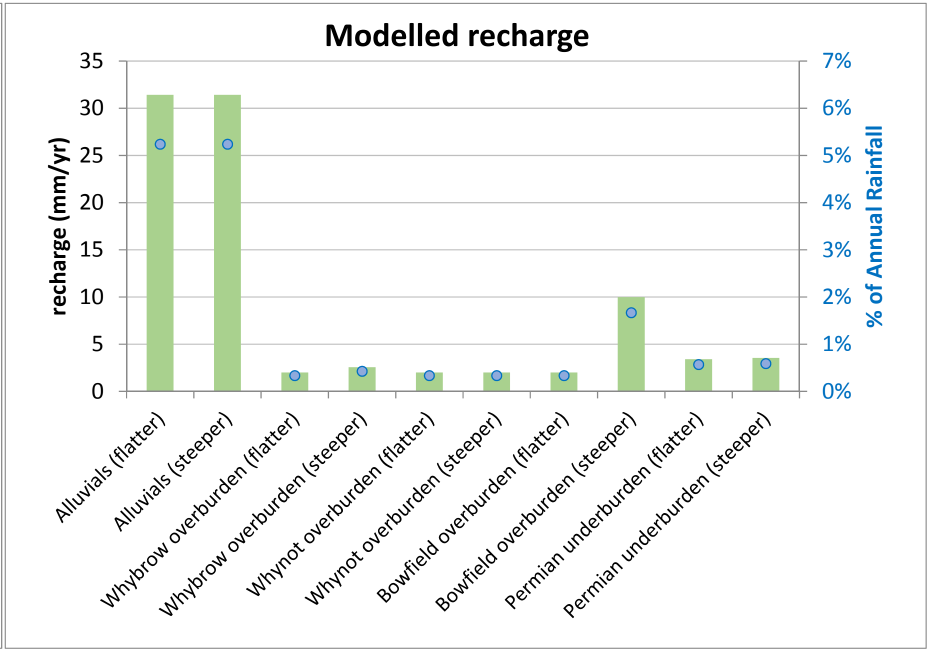




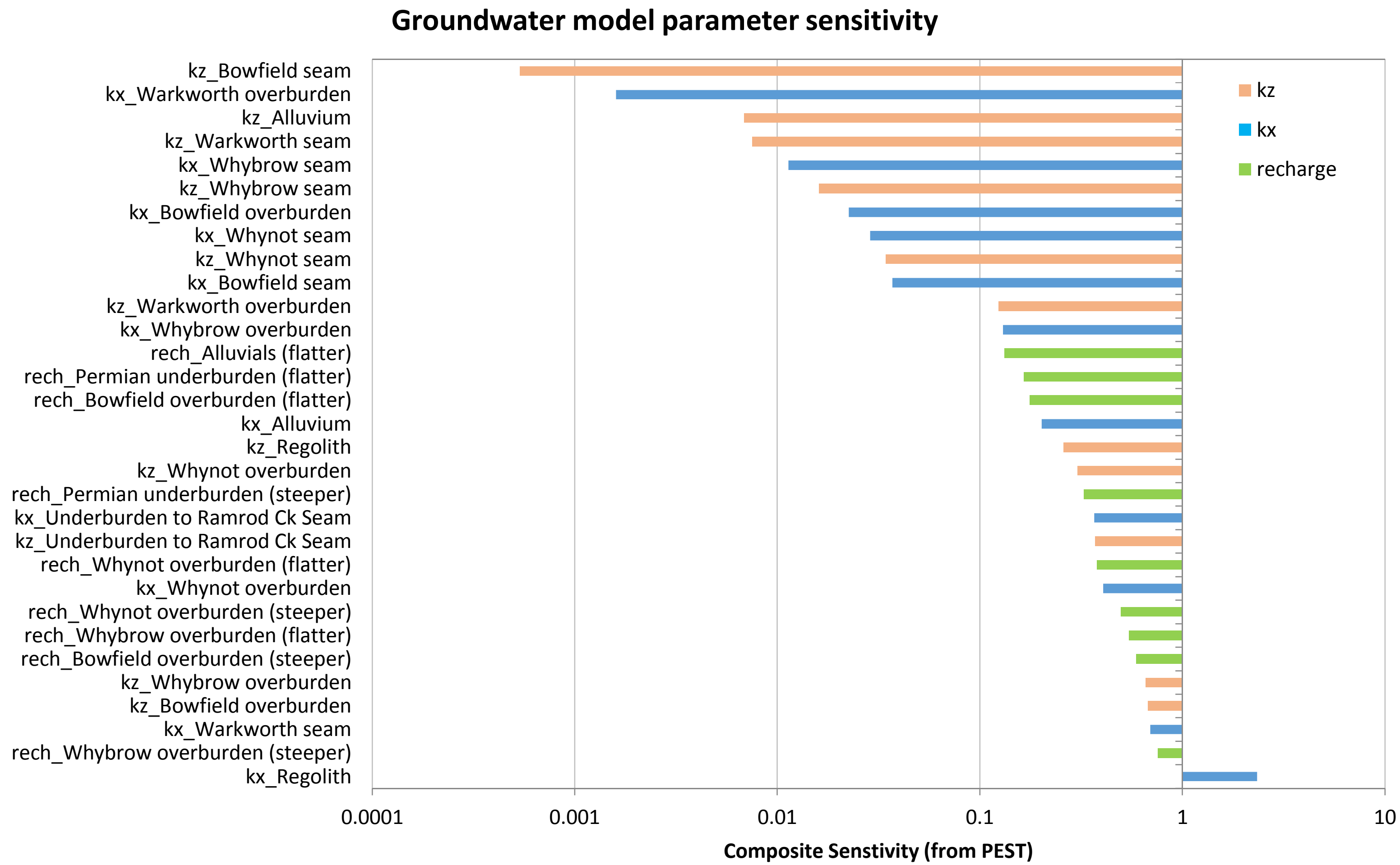
Notes: Parameters from Model run: shv02ss005

D:\Heritage\Spur_Hill\GWModel\SHv02SS\Processing\[SHv2SS005_FinalCalibratedParameters_V2.xlsx]CHART_params

'Steeper / flatter' slope areas defined as >5% rise or <=5% rise, using the hydrologically-forced DEM

HYDRO SIMULATIONS

Modelled hydrogeological parameters **Figure 24**



Notes: senstivities calculated by PEST: shv02ss003.sen__OPT.5

D:\HydroSim\SHC002\GWModel\SHv02SS\Processing\[PEST_ParameterTable_Vistas_Sensitivity.xlsx]Figure 25

Kx = horizontal hydraulic conductivity; Kz = vertical hydraulic conductivity; rech = recharge

'Steeper / flatter' slope areas defined as >5% rise or <=5% rise, using the hydrologically-forced DEM

HYDRO SIMULATIONS

Model Calibration Sensitivity Analysis **Figure 25**